ASTRONOMY

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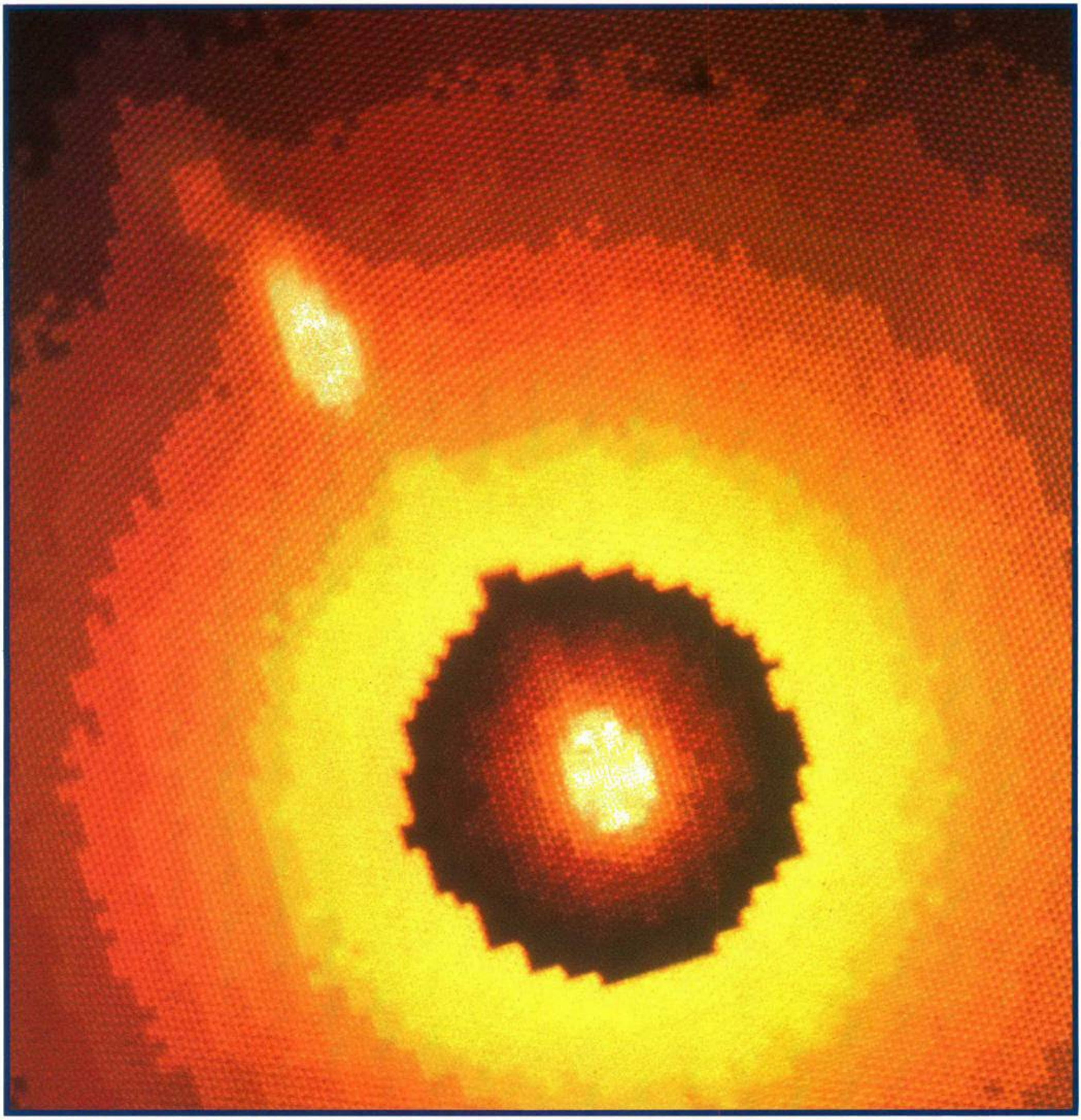
Observing Pluto's Eclipse Events

Inside the Big Bang



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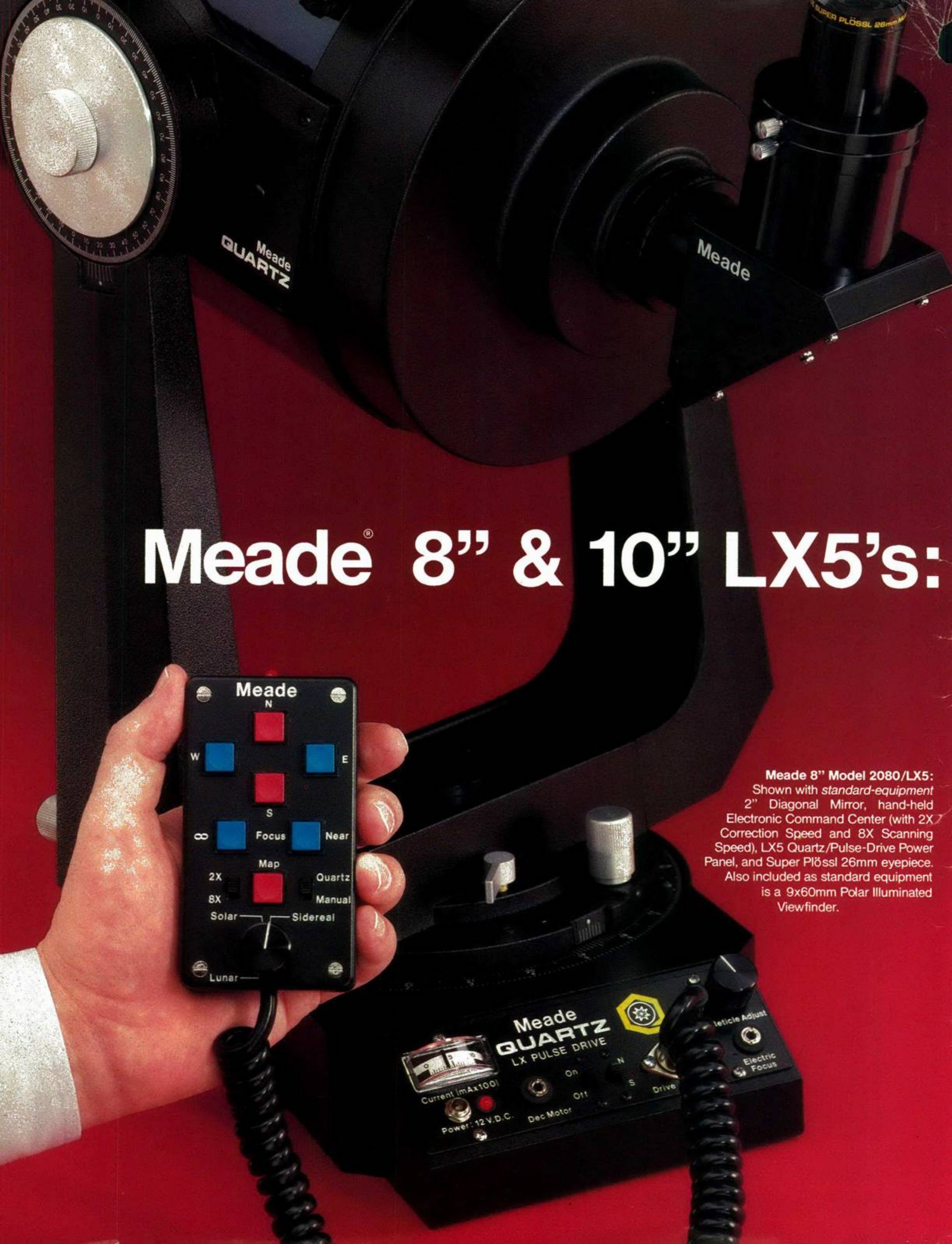

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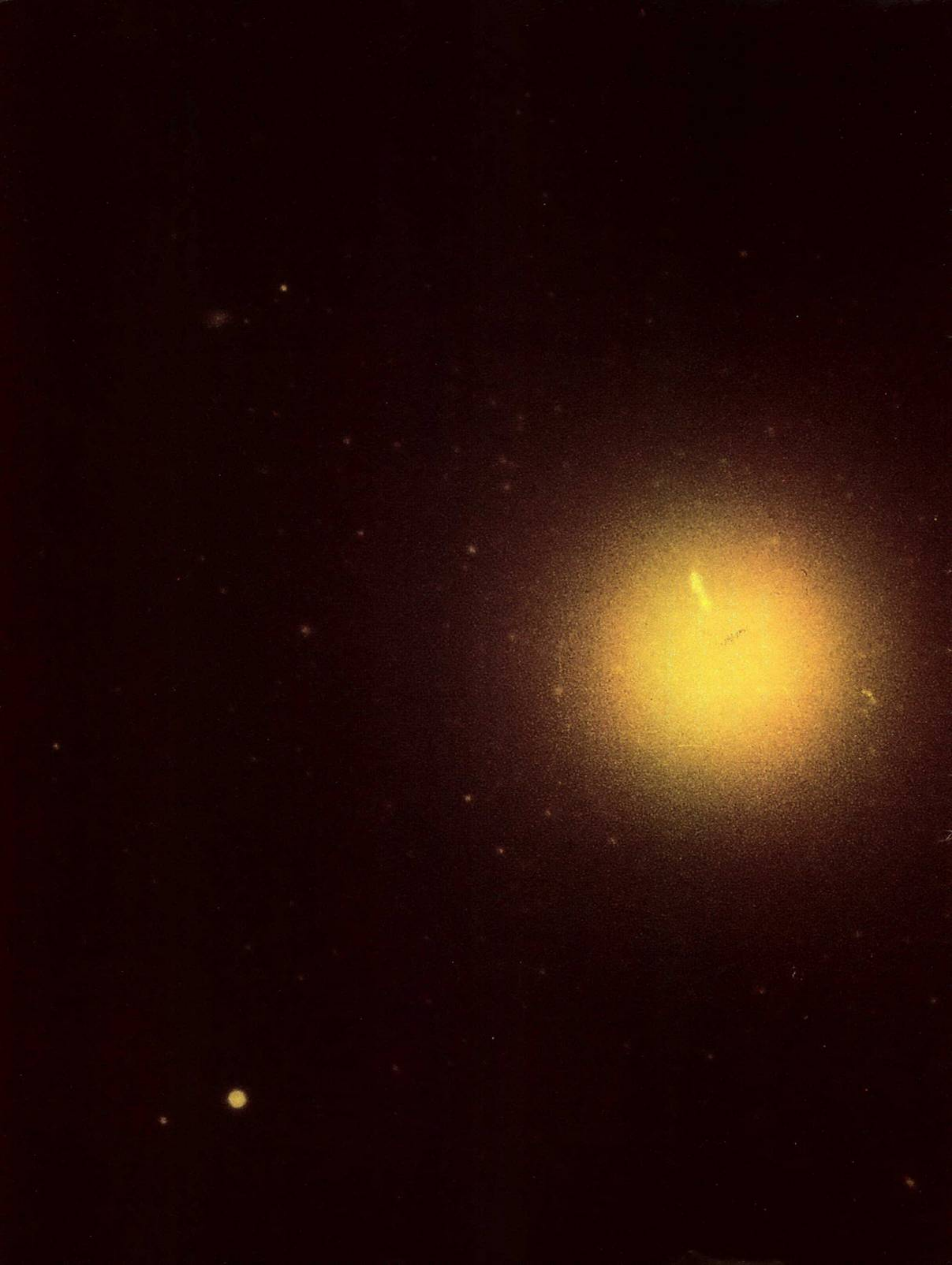

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Cover: One of the most significant features of the giant elliptical galaxy M-87 is a plasma jet issuing from the core at near relativistic speeds. The jet appears as a bulge in the brightness levels of this computer-enhanced view. Image courtesy of the Multiple Mirror Telescope Observatory. These pages: Surrounding M-87 is a halo of thousands of globular clusters, seen here as fuzzy "stars" scattered about the fringes of the bright disk. Photo courtesy of Mount Wilson and Palomar Observatories.

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M-87's jet and accretion disk as they might appear to an observer located several kiloparsecs from the nucleus. Painting by Michael Carroll.

M 87

DESCRIBING THE INDESCRIBABLE

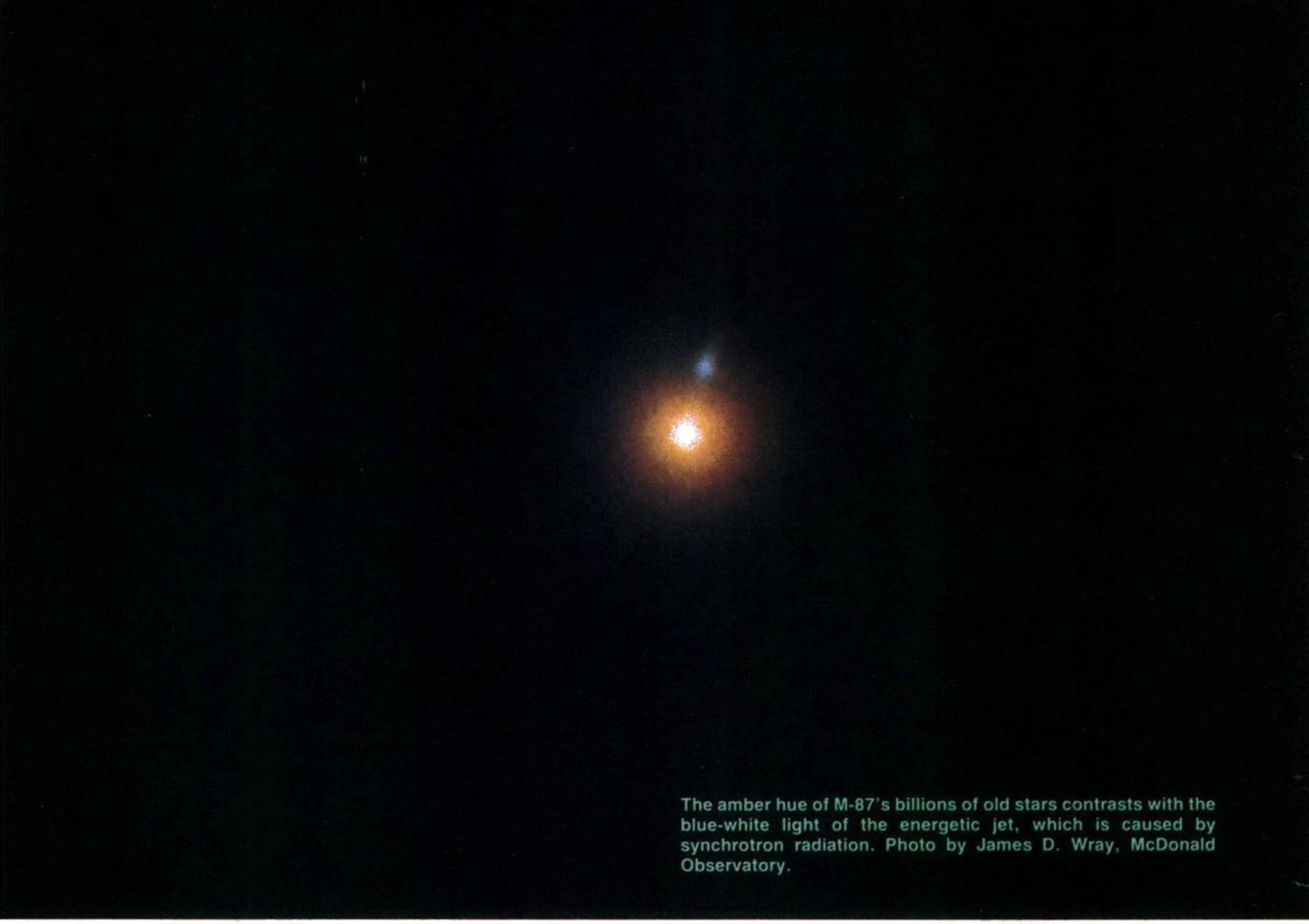
BY JEFF KANIPE

It was six men of Indostan
To learning much inclined,
Who went to see the Elephant
(Though all of them were blind),
That each by observation
Might satisfy his mind.
From "The Blind Men and The Elephant"
by John Godfrey Saxe

At the heart of the Virgo cluster — the nearest rich cluster of galaxies — lies the giant elliptical galaxy M-87. In a universe of "normal" galaxies that emit as much energy as their assemblage of stars produces, M-87 is in the violent minority: it generates about a million times more energy than a typical spiral galaxy, far more than can be attributed to its intrinsic stellar processes. The emissions extend over many frequencies — from radio to x-ray — and most of them derive from a compact source embedded in the core of the galaxy.

In the thirty-eight years since M-87 was first identified with the strong radio source Virgo A, astronomers have endeavored to understand this enigmatic galaxy. In a sense they have been like blind men trying to describe an object they have never really "seen," inferring a beach from a few grains of sand, the ocean from the sound of waves. The precious progress and unforeseen pitfalls of this exploration have made M-87 one of the most important galaxies in research astronomy today.

M-87 is abnormal in many ways. It is unquestionably one of the best candidates for a galaxy with a supermassive black hole in its nucleus (or if not a black hole, some other prodigious engine worth decoding). Moreover, its location at the center of a nearby rich cluster of galaxies makes it an excellent study for astronomers trying to fathom the



The amber hue of M-87's billions of old stars contrasts with the blue-white light of the energetic jet, which is caused by synchrotron radiation. Photo by James D. Wray, McDonald Observatory.

dynamics of galaxy formation and interaction. Furthermore, M-87 is an exceptionally massive galaxy, so it may provide important clues to the nature and amount of "dark matter" that, astronomers suspect, fills the space between galaxies.

Deceiving Appearances

In the viewing field of an 8-inch telescope M-87 is the proverbial "fuzzy star": a round, hazy, gray patch of light with a bright, starlike nucleus. The view doesn't improve much even in large instruments, except that the nucleus appears more intense and slightly less "stellar." M-87 gives the impression of lamplight seen through frosted glass, and no amount of aperture, magnification, or filtering elicits more detail from that implacable, opalescent light. Other than its brightness, it leaves no indelible image in the mind nor a warm place in the heart.

But M-87's telescopic appearance conceals an intriguing feature that lies just a short photographic exposure away. The American astronomer Heber D. Curtis, a salient proponent of the "island universe" theory of galaxies during the early 1900s, first noticed this feature and wrote the following in *Descriptions of 762 Nebulae and Clusters Photographed with the Crossley Reflector*, Lick Observatory, 1918: "A curious straight ray lies in a gap in the nebulosity in position angle 20°, apparently connected with the nucleus by a thin line of matter. The ray is brightest at its inner end, which is 11 arcseconds from the nucleus."

This narrow ray jutting out of the nucleus of M-87 was the first clue something extraordinary was going on. Today astronomers consider the "jet" one of M-87's most significant attributes. However, in 1918 the protuberance was merely a curiosity and evoked little reaction from astronomers who were more involved in the deepening debate over whether or not "spiral nebulae" were actually remote, rotating galaxies similar to our own. Who cared about ferreting out the meaning of a quirky ray sticking out of a bright ball of gas while the fate of a vaster, more dynamic universe hung in the balance?

Thirty-one years later, as radio astronomy developed into an integral branch of observational astronomy, M-87 was identified with the powerful radio source known as Virgo A. Astronomers who recalled Curtis' jet began to take notice.

The situation became more interesting in 1954 when Mount Wilson and Palomar Observatory astronomers Walter Baade and Rudolph Minkowski reported that a significant amount of M-87's radio emission comes from the jet. Baade turned the big telescopes toward the curious feature for a closer look in 1956 and discovered the jet's optical emission was strongly polarized. This polarization was thought to be caused by "synchrotron radiation," in which high-energy electrons spiral along magnetic field lines in the jet at relativistic velocities. As the electrons are accelerated, they emit radiation. The wavelengths at which this radiation occurs depends on the energies of the spiraling particles. In Baade's and Minkowski's case, this was at visual and radio wavelengths. As we will see, synchroton radiation plays a crucial role in helping astronomers understand the physical processes occurring within M-87.

The energy profile of M-87 became more complete in 1966 when M-87 was identified as an x-ray source — in fact it was the first such extragalactic source to be discovered.

Today you can find M-87 in any respectable astronomy textbook under "active galaxies" or "radio galaxies." It is also described as one of the most massive elliptical galaxies known, at least 3 trillion solar masses (a value that seems to be revised upward with every new research paper addressing M-87's mass).

Based on the Hubble classification of galaxies, M-87 is a type E1 elliptical (E0 is the roundest and E7 the most elongated), which means visually this galaxy appears nearly circular. Long-exposure photographs reveal a multitude of fuzzy globular clusters peppered around the fringes of the galaxy like moths around a porch light. Over eight hundred globular clusters have been counted on photographs, but when allowance is made for those hidden by the disk, the number jumps into the thousands. Some astronomers think M-87 could harbor as many as 10,000 globulars, five times the number associated with other Virgo cluster members.

Outburst from the Core

M-87 glows with the yellowed light of old, dying stars. Although elliptical and spiral galaxies are generally about the same age, ellipticals long ago exhausted their quantity of interstellar gas by converting it into stars.

And yet M-87 is not nearly as tranquil as the profile of the typical elliptical suggests. In fact, it is in veritable upheaval. At optical wavelengths the most obvious sign of this upheaval is the jet. Understanding the dynamics of the jet and the nature of the "engine" that drives it has been the focus of much of the M-87 research by astronomers.

Although the jet is too faint to be seen in telescopes, it often appears in amateur astronomers' photographs as a subtle sliver of light emerging from the fuzz on the northwest side of the galaxy (this is actually the galaxy's "north" polar axis). In contrast to the amber glow of M-87, the jet shines with the bluish-white light of synchrotron radiation: its total luminosity is that of 10 million suns. Short-exposure photographs of the galaxy made with large telescopes show a lumpy filament approximately 20 arcseconds in apparent length. At an estimated distance 17 megaparsecs the apparent length of the jet corresponds to a projected length of about 2 kiloparsecs (6,500 light-years) from the outer tip to the nucleus of M-87.

Astronomers estimate that the jet is only about 15,000 years old, and yet it has already reached a length of 2 kiloparsecs. It must be moving at near relativistic velocities, but because the dynamics of the jet are not yet fully understood, astronomers cannot be certain what that velocity is. Many of the estimates of the jet's velocity stem from models, which place the velocity somewhere between 10,000 and 30,000 kilometers per second (although given the length and age of the jet, at a distance of 17 megaparsecs the velocity works out to about 129,000 kilometers per second — 43 percent the velocity of light).

However, even this may be too slow. Some astronomers point out that many radio galaxies exhibit "lobes" of strong radio emission on both sides of the visible object, but that certain classes of radio galaxies (like M-87) and quasars have jets on only one side. These astronomers suggest that M-87's jet is visible to us because it is moving more or less in our direction at speeds close to that of light. Relativistic effects cause the emissions from the jet to be preferentially beamed toward us. If there is a jet on the opposite side, it would be invisible to us because it is beaming its emission away from us in the same manner.

What Makes the Jet Glow

What created the jet and the incredible energy associated with it? To answer this question we need to know what kind of radiation the jet emits. Almost without exception astronomers agree synchrotron radiation produces the jet's light and radio emissions. Unlike thermal radiation, in which electrons in interstellar gas are energized by hot incident radiation, the synchrotron process energizes electrons by accelerating them through a magnetic field. Because synchrotron emission is not dependent on the temperature of the gas medium but on the energy of the particles and the strength of the magnetic field, synchrotron radiation is said to be nonthermal.

In M-87 the synchrotron process begins when electrons are captured in the powerful magnetic field created in the core of the galaxy. The magnetic field accelerates these electrons to relativistic velocities in a spiral path around the magnetic field lines parallel to the polar axis of M-87. As the electrons are accelerated, they emit electromagnetic energy. Because the electrons are moving in a direction perpendicular to the field lines, the radiation is polarized.

To get an idea of what's happening, imagine a group of ice skaters playing a fast game of crack-the-whip on a long and narrow ice rink. The long axis of the rink represents the orientation of the magnetic field lines, the undulating line of skaters (the "whip") delineates the path of the electrons (although only in two dimensions), and the skaters represent energy released by the electrons. As the velocity of the whip increases down the rink, each skater along the line must work harder to maintain the continuity of the line. Eventually the inevitable happens and increased acceleration causes a skater (energy) to fly off from the line (path of electrons) into a snowbank (a radio or optical telescope).

But synchrotron radiation isn't all it's cracked up to be. Though it answers our questions about the kind of radiation we are detecting, it presents us with another problem: How can electrons continue emitting energy as they travel the length of the jet? As energetic electrons emit radiation, they lose energy, and the more energetic they are, the quicker they lose that energy. Typical lifetimes of electrons producing radio energy are a few hundred years, while those generating optical radiation may last twenty or thirty years. Electrons so energetic they emit x-rays last only a few days.

The lifetimes of these electrons are far too short for the electrons to survive the journey out from the nucleus to the end of the jet, even if they travel near the speed of light. What, then, is re-energizing the electrons? Suggestions range from shock waves generated when newer plasma collides with older, slower-moving plasma to turbulence forming between the plasma and the interstellar medium surrounding it. Astronomers are fairly certain, however, that the same regenerating process probably occurs throughout the jet because structures evident in radio maps made of M-87 coincide with those in optical and x-ray emissions.

The Knots Are Not Knots

Photographs of the jet made with large optical telescopes reveal a lumpy protuberance that resembles a bowling pin. The apparent lumps in the jet have come to be called knots and, until recently, were suspected of being shock regions. However, earlier this year astronomers at the Very Large Array (VLA) radio telescope in Socorro, New Mexico, achieved the highest resolution images yet of the M-87 jet, recording detail as fine as 0.1 of an arcsecond, some ten times better than the best resolution of ground-based optical telescopes (equivalent to resolving a quarter fifty kilometers away). The observations reveal quite a different picture of this beguiling feature.

Frazer Owen, a radio astronomer at the VLA, says the jet isn't lumpy as much as it is unresolved.

"The knots you see in most of the optical photographs," Owen explains, "have to do with the fact that the seeing in the optical is typically about 1 arcsecond. And when you smear this particularly complicated image [of M-87] with this kind of seeing, it looks as if there are lots of knots. But when you look at a higher resolution photo, you don't see those obvious spots. There are still areas that are brighter and areas that are fainter, but they don't look like spots. It's not continuous and smooth. It's almost as if the jet is mostly bright and there are little regions that are faint."

Owen's high-resolution observations suggest the jet emissions may be coming from the surface of the jet rather than from inside.

"The jet may be a flow of hot gas out from the nucleus," says Owen, "but the part that is lit up may be a thin layer on the boundary of the jet between the hot gas and the external interstellar medium. And one hypothesis is that the zone of interaction [i.e., the boundary between the jet and the external medium] is what's actually producing the particles that are lighting up the flow."

The Nature of the Beast

Most jets in active galaxies, astronomers agree, lead to their sources, and the source at M-87's core is bright, too bright to be a typical nucleus. In any telescope the galaxy's starlike nucleus appears to burn right through the haze of the surrounding disk. In that locus of light resides the secret of M-87's incredible power. Astronomers want to know what that secret is.

In 1978 Wallace L. W. Sargent and Peter J. Young of the California Institute of Technology investigated the bright core of M-87 and announced that a supermassive object dwells at the center of the galaxy. Their results were based on observations of the "velocity dispersion" of stars at the core of the galaxy.

Velocity dispersion is a spectroscopic measurement of the range of velocities of stars in a galaxy or of the members in a galaxy cluster. In the case of a single star the spectral lines are Doppler-shifted according to how fast and in what direction the star is moving along our line of sight. However, the stars near the core of M-87 lie too close together to be resolved into separate stars. A spectrum of the nuclear region of M-87, then, consists of the composite light of thousands of stars, some of which are moving in our direction, some across our line of sight, and some away from us. Hence, the spectral lines are broadened by an amount that is related to the spread in stellar velocities.

Sargent and Young discovered that the broadened spectral lines of the central luminosity of M-87 implied stars were swirling about the center of the galaxy at abnormal velocities and this velocity increased as the distance from the core decreased. A "central dark mass" of about 5 billion solar masses, they inferred, would provide the kind of deep gravitational "well" necessary to accelerate these stars.

Although many astronomers favor the presence of a black hole (mainly because it is the most efficient means of converting in-falling gas into radiant energy), not all are convinced. Some astronomers have devised models of M-87 that work without evoking a black hole. Alan Dressler of Mount Wilson and Las Campanas Observatories presented evidence in 1980 that the spectrum of the central source of M-87 is actually composed of starlight and suggested that the central source is, perhaps, nothing more exotic than a very dense star cluster. Contrary to Young and Sargent's data, Dressler observed that the velocity dispersion of the stars did not increase near the core, as it would if the stars were being influenced by the gravitational field of a supermassive black hole.

M-87 "Seen" at X-Ray Wavelengths

If your eyes were sensitive to x-rays, you could look up in the sky and see M-87 as a centrally bright, fuzzy, round blob with a diameter slightly larger than that of the Full Moon. The brightest x-ray emitting region corresponds to a diameter of about 200 kiloparsecs, though Eric Feigelson, an x-ray astronomer at Pennsylvania State University, says M-87 doesn't stop there.

"It just gets fainter and fainter," Feigelson says, "and the edge has never been seen. It smoothly falls off."

The total power radiated by M-87 at x-ray frequencies is on the order of 10^{43} ergs per second, which is equivalent to the output of several billion suns. Although it is not the brightest x-ray source in the sky, M-87 is a favorite object of x-ray astronomers for the same reasons it is popular with radio and optical astronomers: it is one of the nearest active galaxies and lies at the center of a galaxy cluster.

"Indubitably many other [more distant] clusters of galaxies have central galaxies like M-87," says Feigelson, "but we just can't see the details."

Within a radius of 100 kiloparsecs from the center of M-87, the galaxy weighs in at an astonishing 10^{12} solar masses and has a temperature of about 20 million Kelvins. One of the most important questions x-ray astronomers must answer is: "Where does this mass come from?" Feigelson believes M-87's location near the center of the Virgo cluster is a determining factor.

"This enormous 10^{12} solar-mass halo of hot gas must come from somewhere," says Feigelson, "and it must be related to the fact that M-87 is at the center of the Virgo cluster. Presumably much of the gas came from the other galaxies in the cluster over the history of the universe."

And yet the clues to the origin of this gas are not so obvious. Although the gas undoubtedly consists of hydrogen and helium — the primeval elements created in the earliest phases of the universe — spectra indicate excessive amounts of heavy metals like iron, neon, and oxygen. These elements could only have been synthesized inside stars. But Feigelson doesn't believe stars alone could have contributed so much to the total mass. "There must be something particular about galaxy clusters that somehow promotes the depositing of all this gas."

Given its location in the Virgo cluster, M-87 could have possibly obtained its mass by "stripping" — a process in which the gas of a small galaxy is gravitationally drawn off by a more massive galaxy as the smaller one passes within its influence. Frequent passes near massive M-87 would deplete a spiral galaxy of much of its star-making gas. And, indeed, in the vicinity of M-87 lie a great many "anemic" spirals, of which M-90 is the best example. The arms of anemic galaxies have few of the characteristically bright star-forming regions (emission nebulae) or clusters of massive, young stars astronomers usually see in spirals. Massive amounts of matter falling onto M-87 may also explain that galaxy's inordinate number of globular clusters.

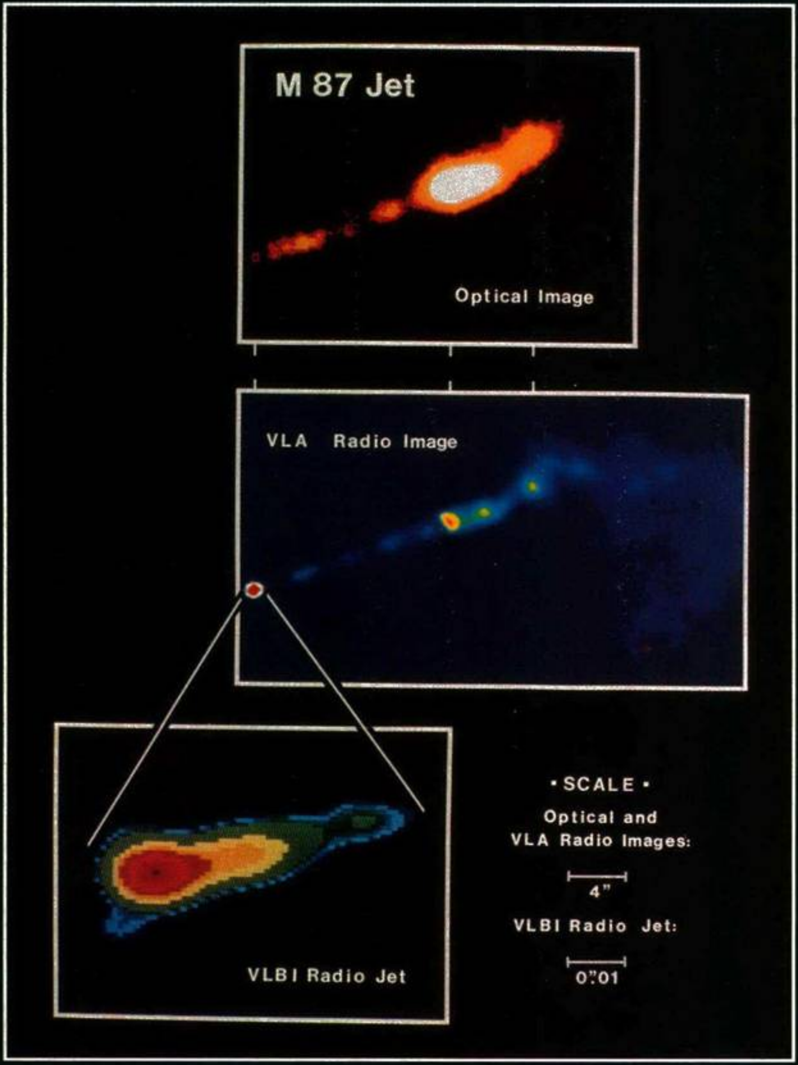
Thus, M-87 may be a gravitational "sink" for the entire Virgo cluster. "The optical astronomer," says Feigelson, "didn't know M-87 was effectively the center of the cluster. [But] in terms of the x-rays and the gravitational potential, it is truly at the center."

And what about the *center of the center* of the galaxy cluster — M-87's mysterious core? What do x-rays tell us about that? It turns out that the observations corroborate those made at optical and radio wavelengths: something is relentlessly drawing the gas into the very middle of M-87.

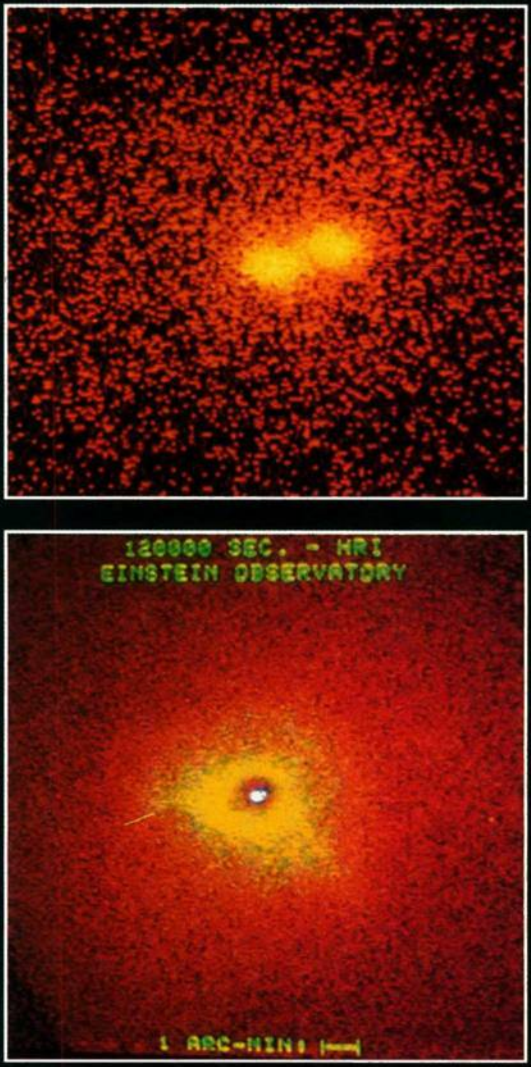
"It is believed that in the inner 10 kiloparsecs [of M-87], the gas is cooling," says Feigelson. For this reason M-87 "is the prototype of an entire study by x-ray astronomers. If the center is cooling and it has less pressure and a lot of gas on top of it, that means [gas] is flowing inward. But it is flowing in very slowly, over billions of years. The estimated rate is between 1 and 100 solar masses a year, though there is a big debate over that. But it is agreed that the gas is flowing in."

And if the gas is flowing in, another important question x-ray astronomers need to answer is: What happens to that gas?

"One would think some of it would turn into stars,"



The CCD optical image at the top shows a bright ionized region within the jet. The middle image was made with the Very Large Array radio telescope at 0.35-arcsecond resolution and shows greater structure throughout the length of the jet. The bottom image was generated by Very Long Baseline Interferometry with forty times the resolution of the VLA image and shows areas of varying radiation intensity in the core — red being the most intense and blue being the least intense. Images courtesy National Radio Astronomy Observatory/Associated Universities, Inc.



X-ray images obtained with the Einstein X-Ray Observatory reveal that M-87 is embedded in a vast corona of hot x-ray emitting gas. In the top image the nucleus and the jet glow brightly amidst a glittering cloud of x-ray photons. The wide-angle view (bottom) shows how the halo of diffuse gas extends many arcminutes in all directions from the center. Images courtesy of Eric Feigelson, Pennsylvania State University.

Feigelson says. "So we should expect to see some star formation occurring in M-87 — but we don't. It's conceivable that a small amount of it might power and feed a black hole in the middle. But one shouldn't give the idea that *all* of [the gas] goes in [the black hole] because there's no way to get so much mass into such a small area. What do you do with 100 solar masses a year? [That question] has been an interesting tempest in a teapot among x-ray astronomers."

More Answers, More Questions

Extragalactic astronomy has come a long way in sixty-three years — from debate over the nature of "spiral nebulae" to the dissection of cores of active galaxies photon by photon. Still, nothing is quite as sobering as comparing what we know with what we have yet to learn. We see M-87 is a tangled cat's cradle of physics. How much farther can we reach, given instrument constraints and our limited understanding of the universe? The answer may be: quite a bit farther.

In 1976 the radio core was resolved down to 2.5 light-months across; in 1983 it was further resolved to 1.5 light-months. Today the increased resolution of radio telescopes has whittled that value down to a matter of light-days.

According to Frazer Owen, "As you look farther and farther in [toward the core of M-87 along the jet], it's like looking at a thin cone. It ends up being opaque out to some distance along the jet at any given frequency. At higher frequencies you can see farther into the core. We're almost certainly looking at the jet as far as you can see in the radio."

Another puzzle piece that has so far eluded astronomers — the velocity of the jet — may soon be found. Owen's team will be comparing high-resolution radio observations of the jet made three years apart to see if any features have moved outward. If the components of the jet are moving at only one-tenth of light-speed, Owen says, no changes will be seen. However, if the velocity is greater, some of the features seen in the recent observations may appear displaced relative to their positions in the older observations. The difference between the two positions can then be used to accurately determine velocity. This value could lead to insights into the dynamics of the jet and, ultimately, what powers it.

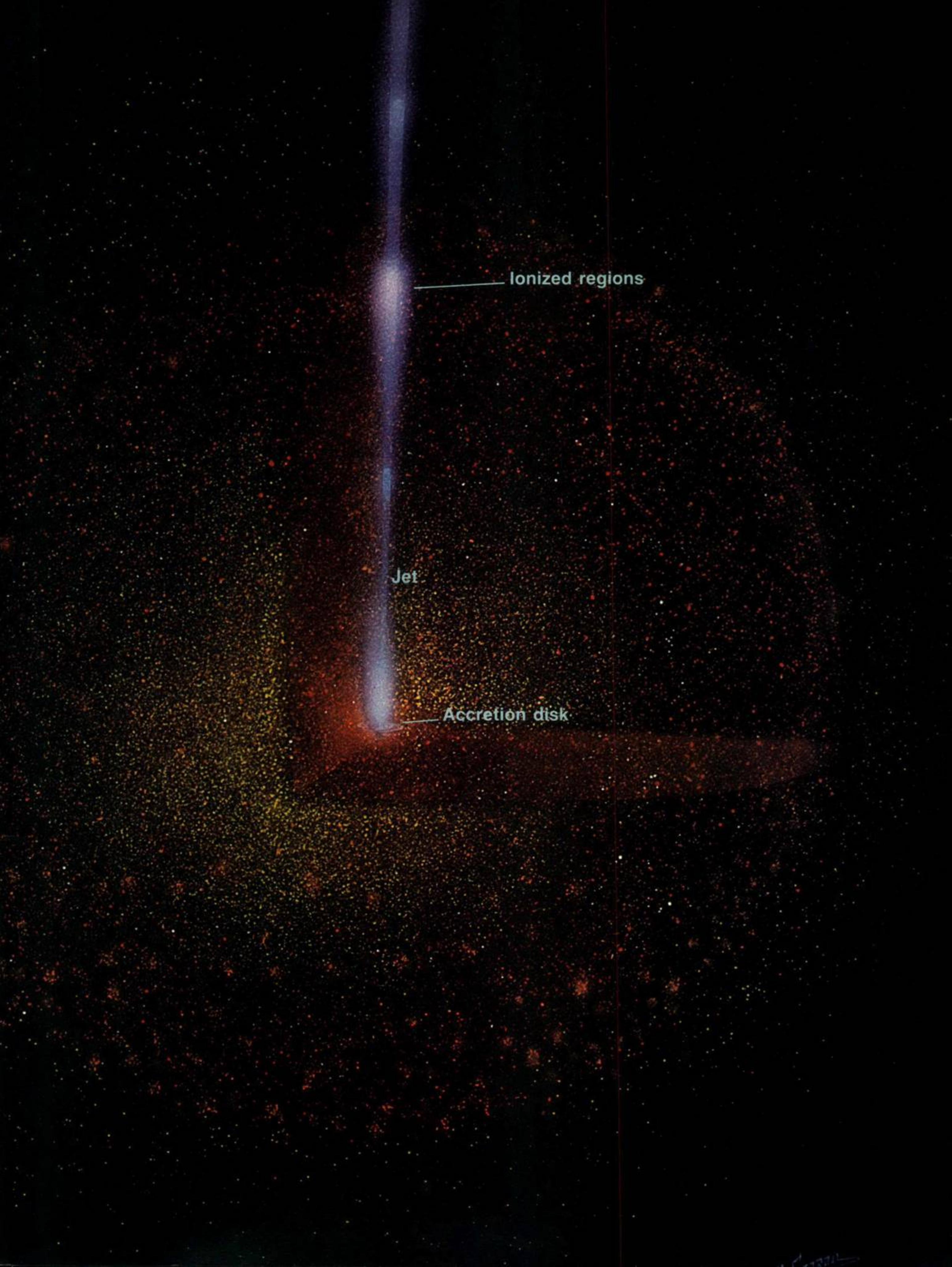
The next major advances in our understanding of M-87 may have to wait until 1989 when the Hubble Space Telescope is finally in orbit and operational. With its estimated one-tenth-arcsecond resolution the Space Telescope may be able to resolve some of the stars producing the broadened spectral lines in the nucleus of M-87 and allow astronomers to establish whether or not the stars are in fact swirling about a supermassive object.

M-87 is only one object in a universe of multifarious objects astronomers are only now beginning to comprehend — a little. Every nugget of information they have about this intricate galaxy has been gleaned one arduous layer at a time. But like a Chinese puzzle M-87 presents many levels, each of which must be explored and understood in order to move on to the next level. And who knows what the next level may reveal about this crucial galaxy?

"One of the things about M-87 that is so difficult and wonderful," says Eric Feigelson, "is that it has many scales, and they all look different. It's sort of like the elephant and the six blind men. It's both a complex and a wonderful object to describe."

Globular clusters

If we could cut away the outer layers of M-87 as in this cross section, we might glimpse an accretion disk at the nucleus, the jet streaming from the accretion disk in a narrow column along the galaxy's spin axis, and bright, ionized regions along the jet, which some astronomers believe represent zones of interaction between the hot plasma and the interstellar medium. Painting by Michael Carroll.


Ionized regions
Jet
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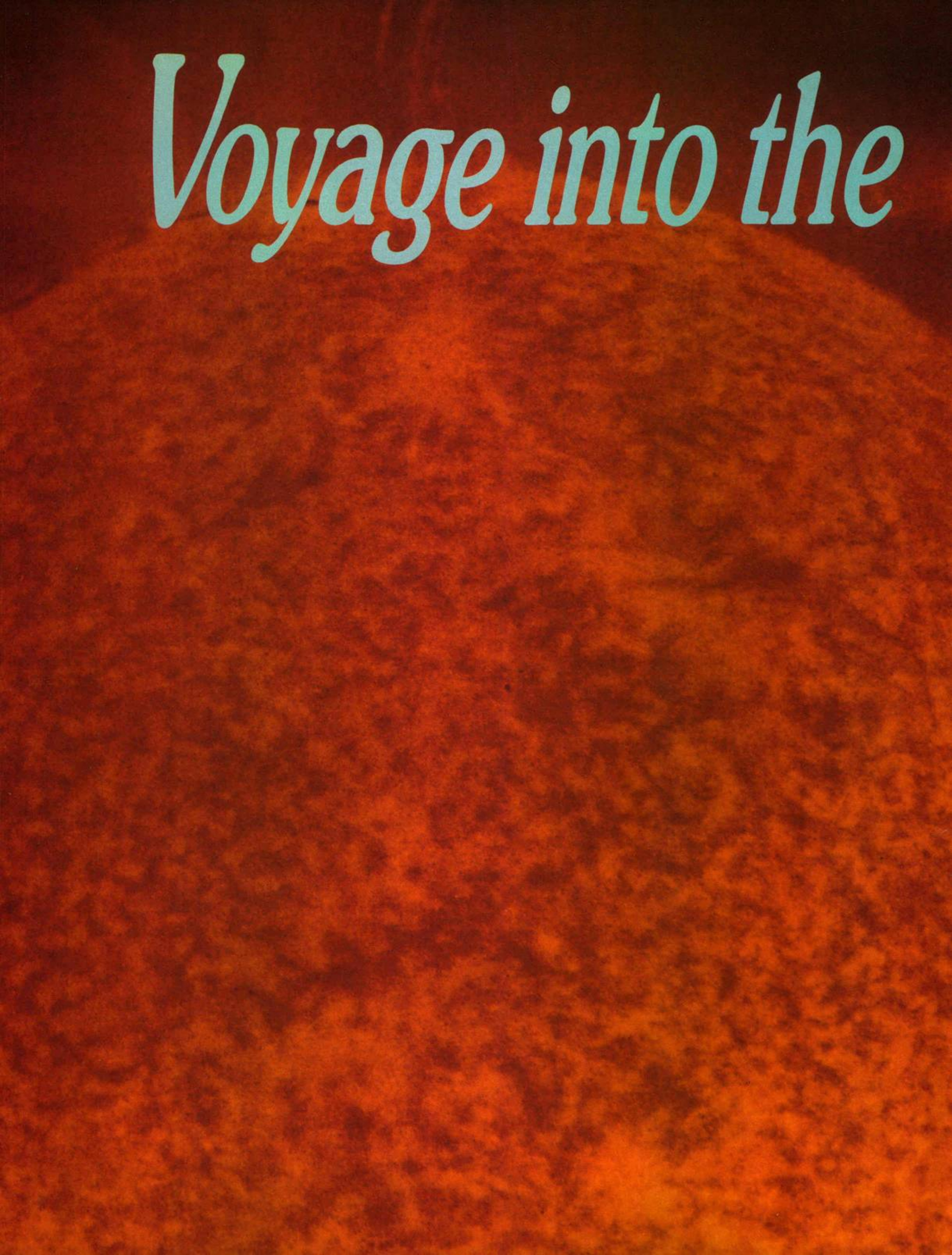
Voyage into the



Third Dimension

by Gary L Bennett

The Ulysses mission will be blazing a new trail when it flies out of the ecliptic plane to study the Sun over both poles.

In 1990 a Space Shuttle will send a spacecraft on a journey into a region of space never before explored — a region that lies in the third dimension of the solar system, out of the ecliptic plane. The spacecraft is named Ulysses in honor of the greatest explorer in Greek mythology. This modern robot explorer, built by the European Space Agency (ESA), will study the Sun from a new vantage point over both solar poles.

Observations of the Sun to date have been restricted to the relatively narrow plane of Earth's orbit — a small sampling of the total, three-dimensional solar environment, which is expected to be much different farther away from the ecliptic. Most observations of the Sun have been made from within 10 degrees of the ecliptic plane. Voyager 1 currently holds the record for the highest elevation — 35 degrees above the ecliptic; Pioneer 11 briefly reached a solar latitude of 17 degrees during its journey from Jupiter to Saturn.

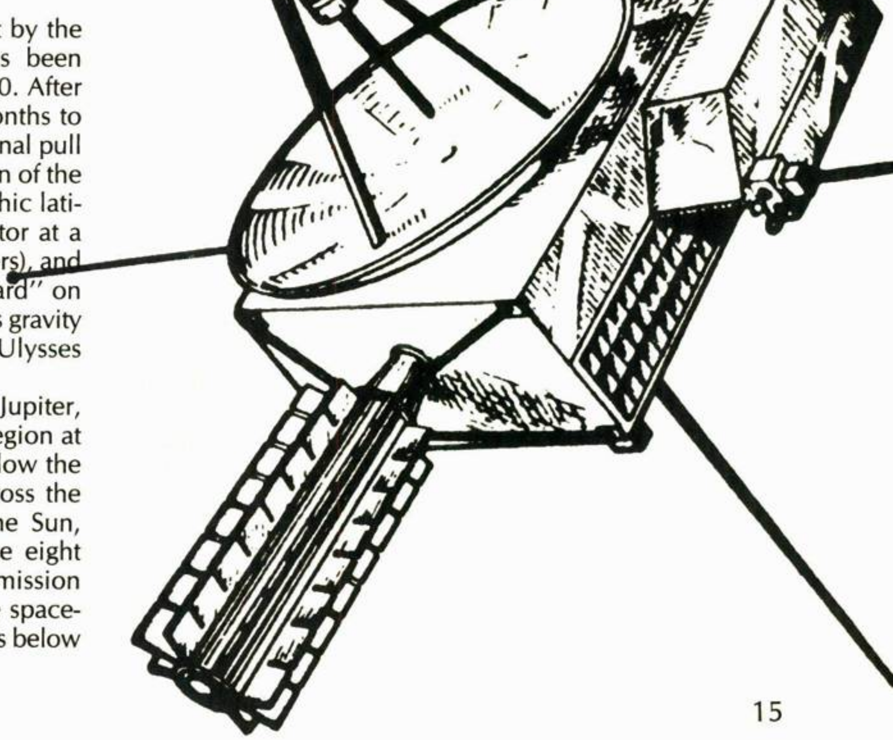
Originally scheduled to be carried into orbit by the ill-fated Challenger in May 1986, Ulysses has been rescheduled for a Shuttle launch in October 1990. After launch the solar explorer will travel fourteen months to a rendezvous with Jupiter. The powerful gravitational pull of the Sun's largest planet will bend the inclination of the spacecraft's orbit to at least 70 degrees heliographic latitude. Ulysses will fly north of the planet's equator at a distance of about 6 Jovian radii (428,000 kilometers), and then Jupiter's gravity will snap Ulysses "southward" on an elliptical orbit back toward the Sun. Without this gravity assist, current launch vehicles could only send Ulysses to solar latitudes of about 40 degrees.

About two and a half years after its flyby of Jupiter, Ulysses will pass over the Sun's southern polar region at a distance of about 2 astronomical units (AU) below the ecliptic. After this polar passage Ulysses will cross the ecliptic at a distance of about 1.2 AU from the Sun, traveling toward a northern polar passage some eight months after the first. ESA considers the baseline mission completed when the heliographic latitude of the spacecraft, on its way to aphelion near Jupiter's orbit, falls below 70 degrees almost five years after launch.

The Original Two-Craft Mission

An out-of-ecliptic mission has long been a goal of space scientists, but fulfilling this goal with the Ulysses mission has not been without difficulties and setbacks. As William I. Purdy, Jr., and Donald C. Stager, both managers in the early stages of the program, have noted, "The need to study the Sun and interstellar space from a vantage point well out of the ecliptic plane was recognized at the dawn of the space age. The concept of a joint American/European program was addressed in a study in 1974, which led to two international symposia to present and discuss the scientific value of an out-of-ecliptic mission."

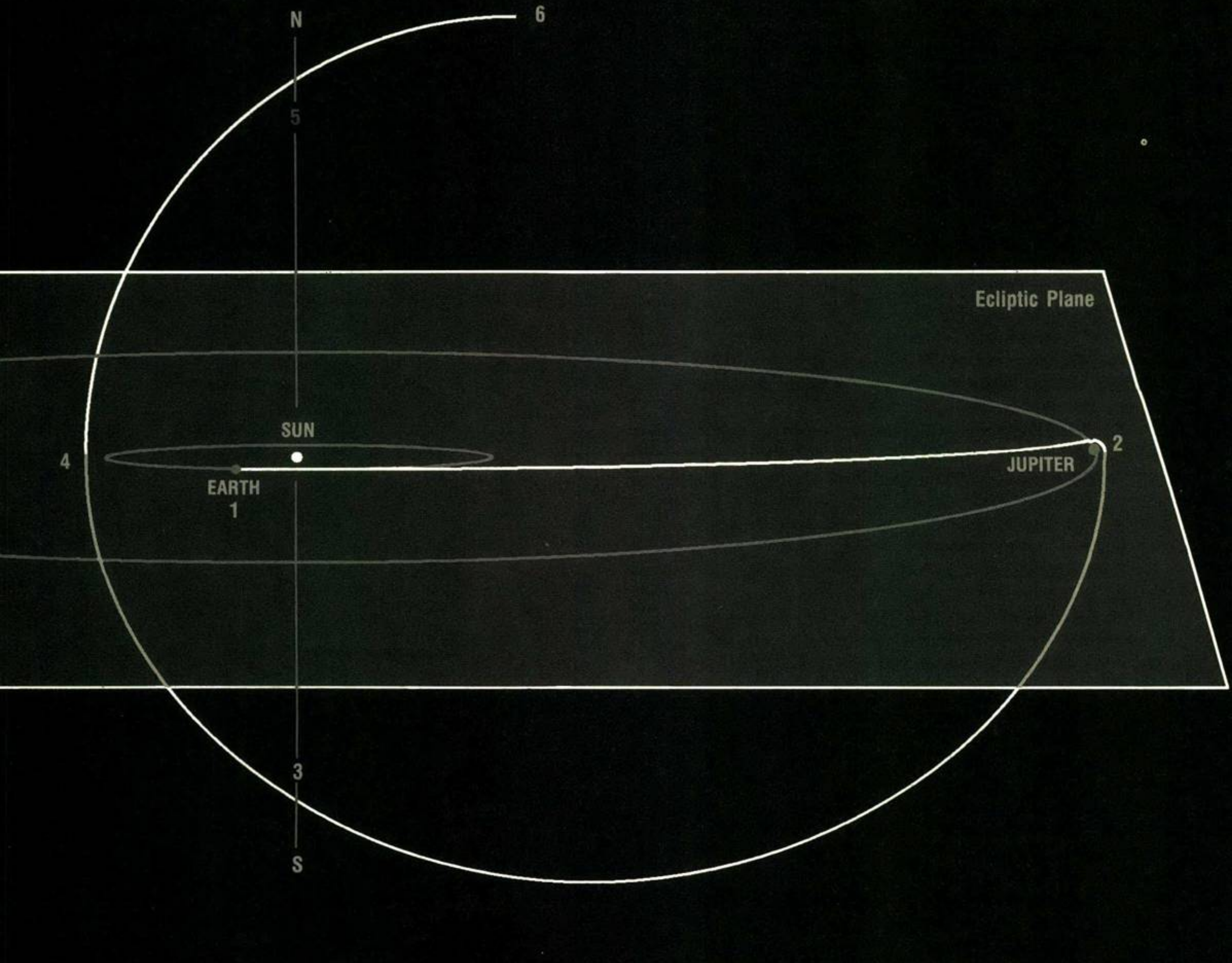
A combined NASA/ESA study group examined the various launch options for such a mission, which included direct injection (the group even considered extra Venus-Earth gravity-assist maneuvers), solar-electric propulsion, and a Jupiter swingby. The first option was rejected



NASA Photo

Ulysses Mission Timetable and Trajectory

Shuttle launch (1)	*October 1990*
Jupiter flyby (2)	*December 1991*
Southern polar passage (3)	*April 1994*
Solar equator crossing (4)	*November 1994*
Northern polar passage (5)	*January 1995*
End of mission (6)	*August 1995*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because it limited the spacecraft to about 40 degrees solar latitude. The second would have achieved 90 degrees solar latitude, but the cost was too high. The third option was selected, provided two spacecraft — one built by ESA, the other by NASA — were flown.

Two spacecraft would permit more experimenters to participate and would allow a stereoscopic view of the heliosphere. This is particularly important because, as Ulysses reseacher W. Ian Axford of Victoria University in Wellington, New Zealand, observed, "the structure of the heliosphere is essentially three-dimensional as well as time-varying. The two-spacecraft option therefore appeared very attractive as a means of eliminating time-space ambiguities." It would also permit simultaneous observations of the northern and southern regions of the Jovian magnetosphere during the Jupiter flyby.

In 1977 ESA and NASA approved the two-spacecraft mission, called the International Solar Polar Mission, and anticipated a Shuttle launch in 1983. NASA, however, canceled its half of the mission as the result of a general budget cut in 1981 and postponed the launch date until 1986. Even though the mission was compromised, ESA decided to proceed with its spacecraft, renamed Ulysses, which was completed in 1984. The Challenger accident in January 1986 forced NASA to again postpone the mission, this time for over four years.

Detecting Diverse Clues

The Sun is not the stable, uniform sphere of light the casual observer sees. As Ulysses flies along its orbit around the Sun it will measure magnetic fields, solar x-rays, heavy ions, energetic particles, plasma waves, and the solar wind — all by-products of complex physical processes occurring within the Sun, on its surface, and in its atmosphere. To complicate matters further, these processes do not occur uniformly over the entire sphere. The solar wind, for example, originates primarily in the polar regions; sunspots form only in the lower solar latitudes.

Consequently, understanding the Sun requires observations from all solar latitudes. This is the goal of Ulysses. As Ulysses' detectors measure the magnetic fields and particles that travel away from the Sun in all directions far into interplanetary space, astronomers and physicists will be receiving new clues about how our Sun works.

Aside from being the key to life on Earth, the Sun is a vast astrophysical laboratory that can provide information essential to understanding other stars — and to developing the almost unlimited electrical power of nuclear fusion. The Sun is a seething caldron of nuclear fury twisted by vast electromagnetic forces, which formed out of the collapse of the original solar nebula over 4.5 billion years ago. The Sun, almost 1.4 million kilometers across, is large enough to contain the volume of about 1.3 million Earths.

Most of the mass of the solar system — 99.8 percent — is contained in the Sun. On average the Earth is denser than the Sun: 5.5 versus 1.4 grams per cubic centimeter. The solar density is estimated to range from about 160 grams per cubic centimeter (fourteen times the density of lead) in the interior to one-billionth gram per cubic centimeter at the visible surface, or photosphere. The density drops even more in the solar "atmosphere."

The energy that lights the Sun comes from the core, a relatively small volume within a dense sphere about one-quarter the diameter of the visible Sun. Here protons fuse into deuterons, which in turn fuse into helium nuclei at temperatures of about 15 million Kelvins and pressures 400 billion times the atmospheric pressure on Earth. From this and other reactions photons are released. Over a complex journey lasting some 10,000 to 100,000 years the descendents of these photons carry their energy across a shell that makes up about 60 percent of the Sun's radius.

The Influence of Magnetic Fields

Outside this shell the temperatures are low enough for partially ionized atoms to form and capture the photons. This sets up a complex convective flow of hot gas that bubbles in granular and supergranular cells across the outermost 15 to 20 percent of the solar radius.

The motion of the electrically charged particles in this convective zone constitute electric currents. The currents in turn generate large magnetic fields. Twisting and stretching like rubber bands, these fields occasionally surface to form sunspots. The magnetic fields drive a whole range of other solar activity such as the sudden, violent bursts of solar flares and the graceful arches of the prominences and filaments formed by the condensation of material flowing from the corona into the chromosphere.

The photosphere is a 400-kilometer-thick shell consisting mostly of hydrogen (73.5 percent) and helium (24.9 percent) with trace amounts of other elements. Most of the Sun's energy is radiated from the photosphere. Above the photosphere is a 5,000-kilometer-thick shell called the chromosphere, which is covered by the corona, a tenuous high-temperature gas envelope that stretches beyond the Earth.

The magnetic fields originating in the photosphere shape the corona and the fundamental processes that send the solar wind into interplanetary space. Active regions of the photosphere contain closed magnetic loops spanning areas of opposite polarity. These are areas of both high temperature and high density. Above these active areas coronal streamers rise into interplanetary space.

At the solar poles are areas of weak magnetic fields, called coronal holes, where the magnetic fields are open. Because they're not contained by a closed loop, particles are able to stream away from the Sun as the solar wind. The electrons, protons, and heavier ions that make up the solar wind rapidly spread out from the poles carrying the magnetic field with them to the outer reaches of the heliosphere, an estimated 100 AU distant.

Leaving the Muddled Ecliptic

These solar-wind particles provide important information about the chemistry and physics of the solar atmosphere. However, as Ulysses science team members Klaus-Peter Wenzel and Richard G. Marsden of ESA and Edward J. Smith of the Jet Propulsion Laboratory have commented, "observations in the ecliptic plane are difficult to interpret since the particles can originate and propagate through a variety of different regions in the corona, with the result that the composition and spectra we observe are the products of a complicated mixture of processes. At different heliographic latitudes the mixture of processes involved is expected to be different and perhaps simpler." By traveling out of the ecliptic, Ulysses will reach these latitudes.

One reason for the complicated structure of the solar wind near the ecliptic is the rotation of the Sun. Solar-wind particles move radially away from the Sun in all directions and would continue in a straight line if the Sun was stationary. But a rotating Sun causes the solar-wind stream to take on a spiral shape, like that of water leaving a spinning garden sprinkler. And since the magnetic field is carried by the electrically conductive solar wind, it too takes on this shape at low latitudes. Above the poles the solar wind and magnetic fields are expected to be substantially less tangled.

Another complicating factor originates with the dipole nature of the Sun's magnetic field. The fields leaving the solar poles with the solar wind are of opposite polarity, and as they fan out from the polar regions they eventually meet at a distance of about 2 solar radii to form a neutrally charged sheet extending from the solar equator. As the Earth moves around its orbit, which is slightly inclined to the solar equator, it moves in and out of the neutral sheet and the polarity of the magnetic field alternates.

Solar-wind particles are also affected by this neutral zone. The speed of the solar wind, which ranges from 200 to 900 kilometers per second, is always low over a neutral zone. High-speed particle streams emanating from the polar regions overtake these low-speed streams, causing pronounced stream-stream interactions that appear as plasma waves. Ulysses scientists hope the solar wind out of the ecliptic plane, traveling at a constant speed with untangled magnetic field lines, will provide a less complicated object of study than the solar wind in the ecliptic.

Ready for the Unexpected

The instruments Ulysses carries over the poles of the Sun will give astronomers and solar physicists a better understanding of the Sun and the interstellar environment through which our solar system moves. The relatively simpler environment at higher solar latitudes is not only an improved laboratory for particles and rays leaving the Sun but also a good place to detect those entering our solar system, such as cosmic rays, gamma rays, and neutral helium atoms.

Ulysses will be breaking new ground when it leaves the ecliptic: some of its instruments will make measurements that have never been made before. Ulysses scientist John A. Simpson of the University of Chicago and his colleagues stated that "the instrumentation [Ulysses] carries must be appropriate both to an exploratory mission, with the wide range of measurements and responses necessary to encompass unexpected phenomena, and to a mission on which definitive measurements must be made."

With its nine sophisticated scientific instrument packages Ulysses provides such capabilities. It is ready to measure, in the words of the official NASA/ESA statement of its goals, "for the first time as a function of solar latitude, the properties of the solar wind, the structure of the Sun/wind interface, the heliospheric magnetic field, solar radio bursts and plasma waves, solar x-rays, solar and galactic cosmic rays, and the interstellar/interplanetary neutral gas and dust." Secondary objectives include the detection of cosmic gamma-ray bursts, a search for gravitational waves, and measurements of the Jovian magnetosphere.

A pair of magnetometers attached to the end of a long boom will map the Sun's magnetic fields as well as the interplanetary magnetic field and the Jovian magnetosphere. The shape and structure of the fields detected at the spacecraft as it passes over the solar polar regions is most important because this information can be used to deduce the nature of the magnetic fields at the poles.

A Solar-Wind Inventory

A precise inventory of solar-wind particles is the task of the solar-wind plasma experiment. As Ulysses moves from the solar equator toward the poles, the plasma instrument will measure the change in energy and number of the protons, electrons, and heavy ions in the solar wind. The particle streams over the poles should be free of the complications caused by the collision of high-energy and low-energy streams at the solar equator.

By analyzing the mixture of ions in the solar wind and measuring their temperatures, scientists hope to pinpoint the sources of the solar wind in the corona. The solar-wind ion-composition spectrometer will study the speed and temperature of each type of particle — from hydrogen to iron atoms — as well as its degree of ionization. Since these characteristics are determined by the temperature of the corona in which the ions originated, they are direct indicators of conditions in the corona.

This coronal heating process, however, cannot account for the medium- and high-energy particles in the solar wind, which require a different — and as yet unknown — mechanism to achieve their high energies. Another unsolved problem is how the corona temporarily stores these particles before eventually releasing them into interplanetary space. An energetic-particle-composition experiment on board Ulysses will measure the intensities, spatial variation, energies, and masses of the medium-energy particles.

The energetic-particle-composition experiment will also be looking for particles coming from the Milky Way. A lithium fluoride detector, originally planned for the NASA spacecraft, has been incorporated into this experiment to measure the distribution of interstellar neutral helium that is penetrating into the heliosphere. These measurements will further the understanding of the distribution of interstellar gas — the remnants of dead stars and the life-giving material of new ones.

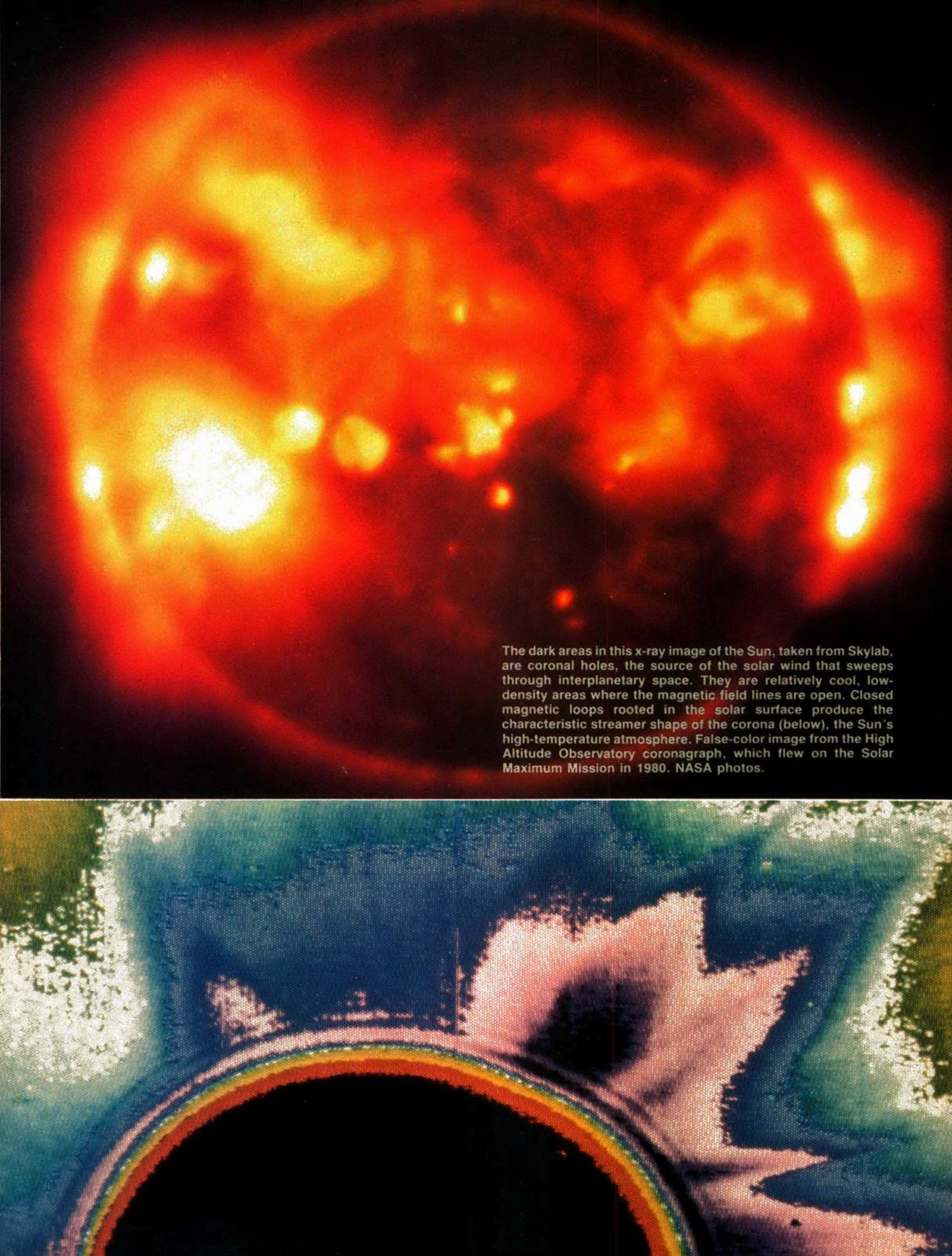
Ions and electrons with a broad range of energies will be studied by the HI-SCALE instrument — the Heliosphere Instrument for Spectral, Composition, and Anisotropy at Low Energies. Scientists hope to gain information on the mechanisms that release solar-flare particles, the physics of the corona, and the Sun's composition.

Searching for Cosmic Rays

The outward-flowing solar wind sweeps away low-energy galactic cosmic rays from the ecliptic plane, which deprives us of clues to astrophysical processes occurring elsewhere in the Galaxy. A cosmic-ray and solar-particle instrument will detect these cosmic rays, especially the low-energy particles that cannot penetrate to the ecliptic, in their almost pristine form.

A unified radio and plasma-wave experiment consisting of a pair of wire booms and an axial boom will study the radio signals emitted by the Sun and the plasma waves in the solar wind. By sensing the plasma-wave frequencies as they pass the spacecraft, scientists hope to understand the physics of plasmas, the clouds of electrically charged particles that travel as plasma waves in the solar wind.

A group of four sensors, known as the solar-flare x-ray and cosmic gamma-ray burst experiment, will be used to study the x-rays emitted by solar flares and gamma rays entering the solar system. Because it's making measurements above the ecliptic, Ulysses will allow the height of the x-ray source in the solar atmosphere to be calculated. In a similar fashion Ulysses will provide a triangulation point for precisely locating the sources of cosmic gamma-ray bursts. These bursts are thought to be generated on or near neutron stars.

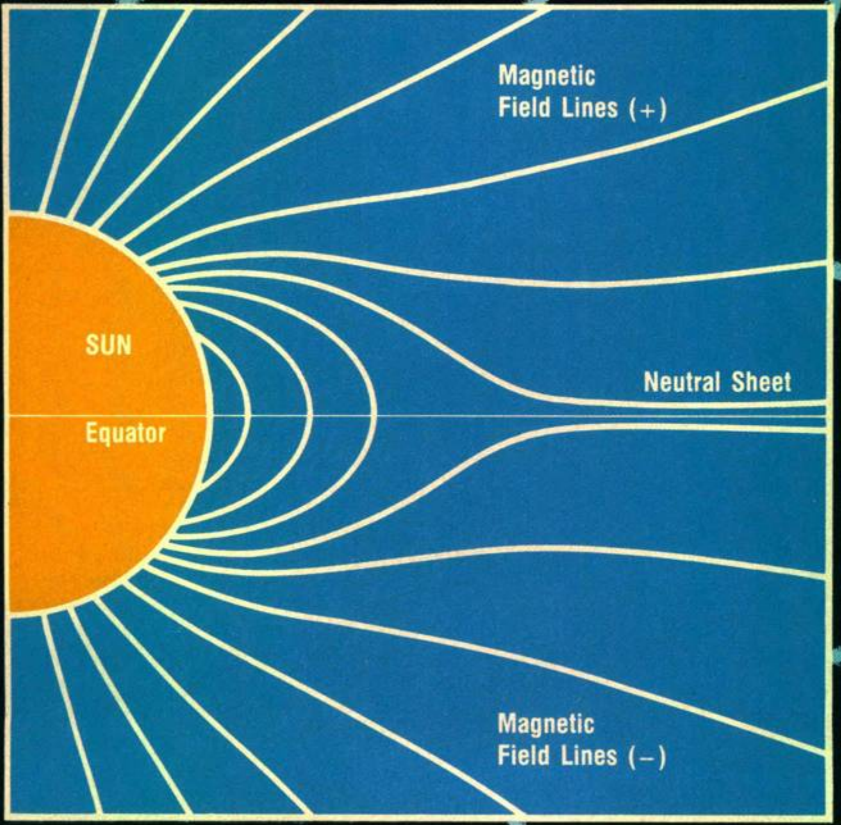


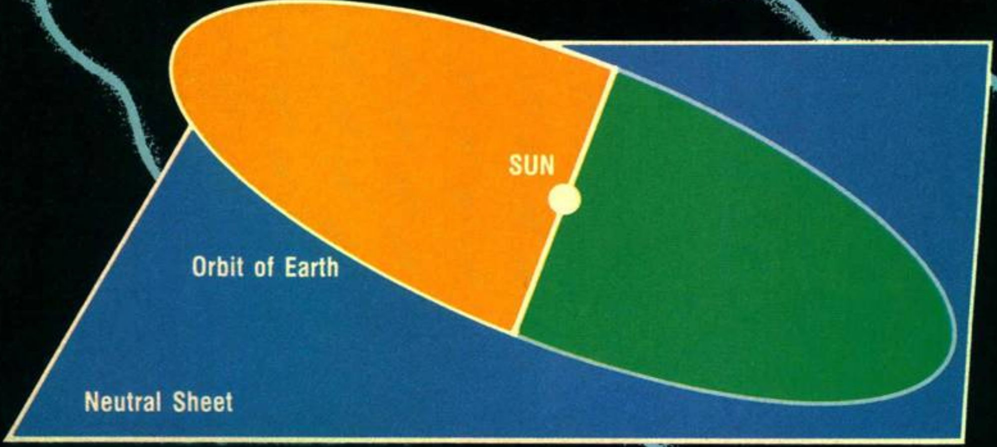
The dark areas in this x-ray image of the Sun, taken from Skylab, are coronal holes, the source of the solar wind that sweeps through interplanetary space. They are relatively cool, low-density areas where the magnetic field lines are open. Closed magnetic loops rooted in the solar surface produce the characteristic streamer shape of the corona (below), the Sun's high-temperature atmosphere. False-color image from the High Altitude Observatory coronagraph, which flew on the Solar Maximum Mission in 1980. NASA photos.

A Problem of Perspective: Solar Activity in the Ecliptic

When Ulysses flies far out of the ecliptic plane, it will get a view of the Sun that is different from and much simpler than what we can see from Earth. Several factors conspire to complicate our view: the dipole nature of the Sun's magnetic field, the slight inclination of Earth's orbit to the solar equator, and the rotation of the Sun.

Magnetic field lines near the solar equator are twisted into spirals as the Sun rotates (right); field lines near the poles are expected to be less distorted. As the field lines diverge from the polar regions, each of which has an opposite overall charge, they meet to form a neutrally charged sheet (below), where low- and high-energy particles mix. Since Earth's orbit is inclined 7 degrees to the solar equator and this neutral sheet (bottom), we alternately pass between areas of positive and negative charges.


Magnetic Field Lines (+)
SUN
Neutral Sheet
Equator
Magnetic Field Lines (−)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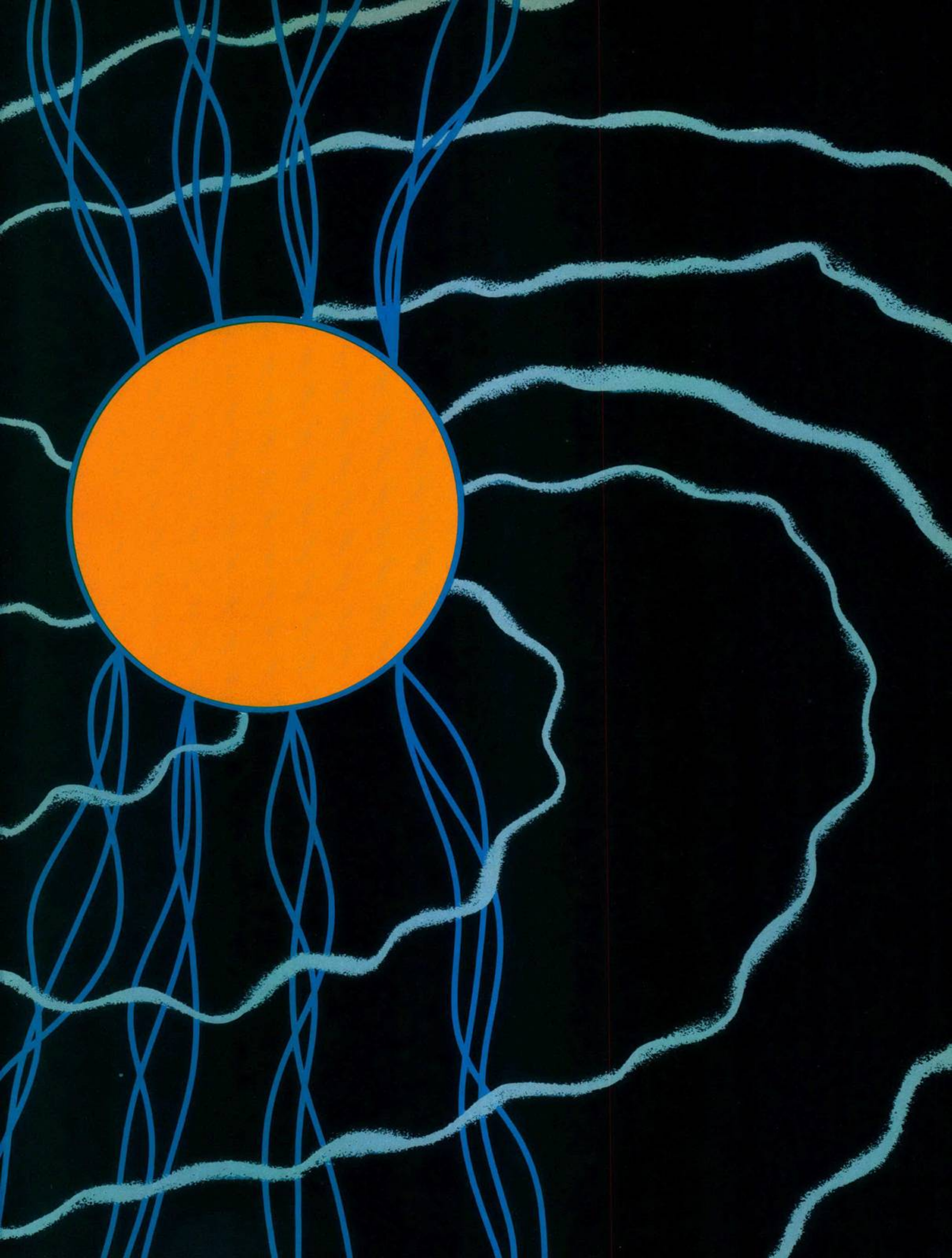
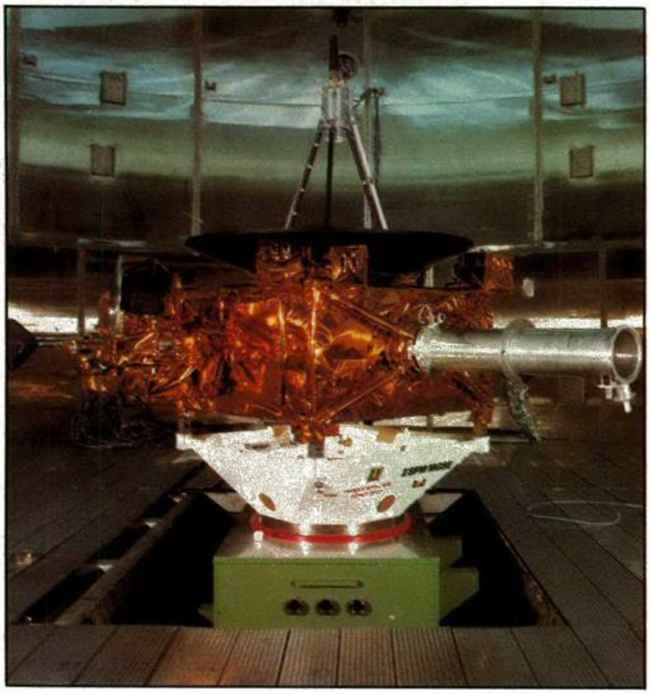




Detecting solar radio bursts and galactic cosmic rays are two of the nine experiments Ulysses will conduct during its five-year mission. European Space Agency photo.

To aid our understanding of how circumstellar dust shells develop, Ulysses will carry an instrument to measure the mass, speed, flight direction, and electric charge of individual dust particles. The Sun is surrounded by a flat plate of dust composed mostly of silicate grains at a distance of about 4 solar radii from the Sun. This dust, thought to be the cause of zodiacal light, may be material left over from the formation of the planets. There may also be a second dust cloud composed of smaller particles, some of which are of extra-solar origin, at higher solar latitudes.

Some of these dust particles undoubtedly originated beyond the solar system. Other particles most likely came from comets and from destructive collisions between asteroids. The measurements made by the Ulysses dust experiment should allow scientists to determine the significance of these three possible sources of dust. Ulysses will also measure the three-dimensional dust distribution around Jupiter.

Aside from conducting these nine experiments with special instrument packages, Ulysses will use the radio signals it sends to and receives from Earth to conduct two additional experiments: coronal sounding and detection of gravitational waves. Using the radio science equipment on Ulysses to send and receive signals near times of superior conjunctions, ESA researchers in West Germany will study the coronal plasma. In particular, scientists will use this coronal-sounding experiment to measure the density, turbulence, and velocity of the coronal plasma in regions presently inaccessible to in situ measurements.

Gravitational waves, predicted by Einstein's theory of general relativity, are spatial strains moving at the speed of light. Scientists expect these waves to be generated by the violent collapse of stars, galactic nuclei, or other astrophysical objects into supermassive black holes. Through very precise tracking of Ulysses, using two-way Doppler data, detecting low-frequency (about 0.001 hertz) gravitational waves should be possible.

An Autonomous Spacecraft

Ulysses will be tracked by the 34-meter dishes of NASA's Deep Space Network (DSN) from the Ulysses Flight Operations Center at JPL's Mission Control and Computing Center. The spin-stabilized spacecraft will keep the centerline of its 1.65-meter high-gain antenna pointing continuously to Earth. Normally the DSN will track Ulysses only about eight hours per day, which means the spacecraft must store data for later transmittal interleaved with its real-time data transmissions.

Because of the limited period of tracking and the long signal travel time between Earth and Ulysses, the spacecraft was designed and built to be autonomous. It can detect failures and correct them. It is even programmed to search for and reacquire Earth contact if no commands are received after a preselectable time of up to thirty days.

The basic spacecraft is an aluminum boxlike structure with two overhanging "balconies." Mounted on this structure are most of the sensors, a hydrazine-fueled propellant tank used for trajectory and attitude control, and all electronics units of the scientific instruments and spacecraft subsystems. Magnetic and gamma-ray sensors are located on a 5.6-meter-long radial boom. Three antennas, consisting of a 7.5-meter-long axial boom and two radial wire booms measuring 72.5 meters tip to tip, will measure plasma waves and traveling solar radio bursts.

Because Ulysses will be traveling to Jupiter, where the sunlight is less than 4 percent of that on Earth, it must carry a power supply that is independent of the Sun. NASA received a radioisotope thermoelectric generator (RTG) from the U.S. Department of Energy for use on the spacecraft. This power source, which is based on the technology successfully employed on the Voyager spacecraft, provides about 280 watts of electrical power at the beginning of the mission.

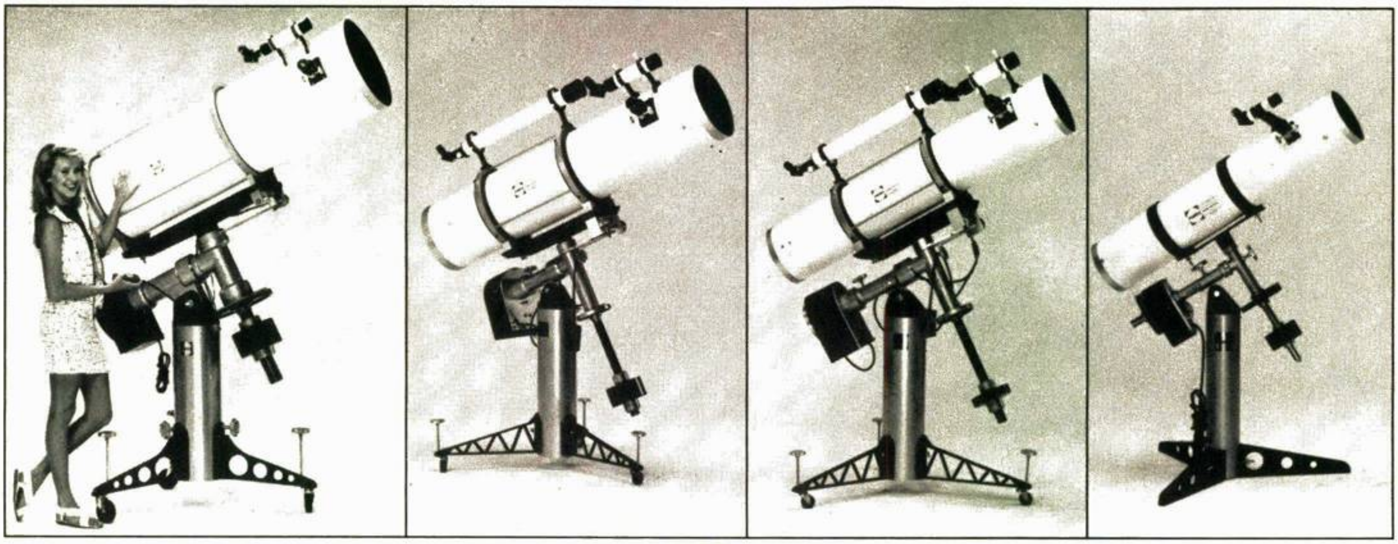
Ulysses has a mass of 370 kilograms, of which 55 kilograms are made up of the scientific payload. With its booms stowed, the spacecraft is 3.2 meters by 3.3 meters by 2.1 meters.

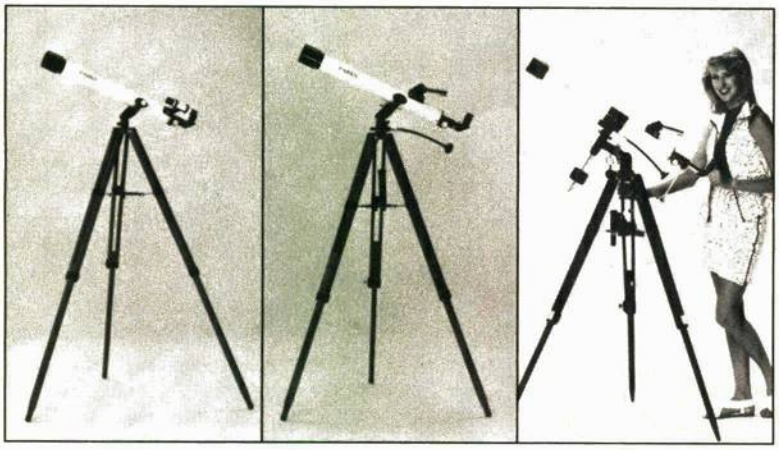
A Space Shuttle will carry Ulysses into an orbit about 250 kilometers above the surface of Earth. Inside the cargo bay of the Shuttle, Ulysses will be mounted atop a three-stage launch vehicle made up of a two-stage Inertial Upper Stage (IUS) and a Payload Assist Module version S (PAM-S). The astronauts will open the Shuttle's cargo bay doors, exposing Ulysses to space. They will then begin a series of check-outs of Ulysses, the Shuttle, and the IUS/PAM-S/Ulysses system and establish a safe separation distance to avoid the exhaust of the IUS/PAM-S.

When the correct attitude has been achieved, the IUS/PAM-S upper stage will sequentially fire its three stages, which will thrust Ulysses out of Earth orbit. Before the PAM-S ignition, Ulysses and the PAM-S stage will be spun up to about 60 rpm for stability. After the PAM-S burn and the deployment of the spacecraft booms, the spin rate of Ulysses will be reduced to 4.7 rpm. Ulysses will then have left Earth forever. Five years later, scientists will have a new understanding of the life-giving star we call the Sun.

Gary Bennett, deputy director of the U.S. Department of Energy's Division of Special Applications, manages the department's radioisotope power source projects for space applications. His last article, "Return to Jupiter" in the January 1987 issue, described NASA's Galileo mission.

PARKS . . .





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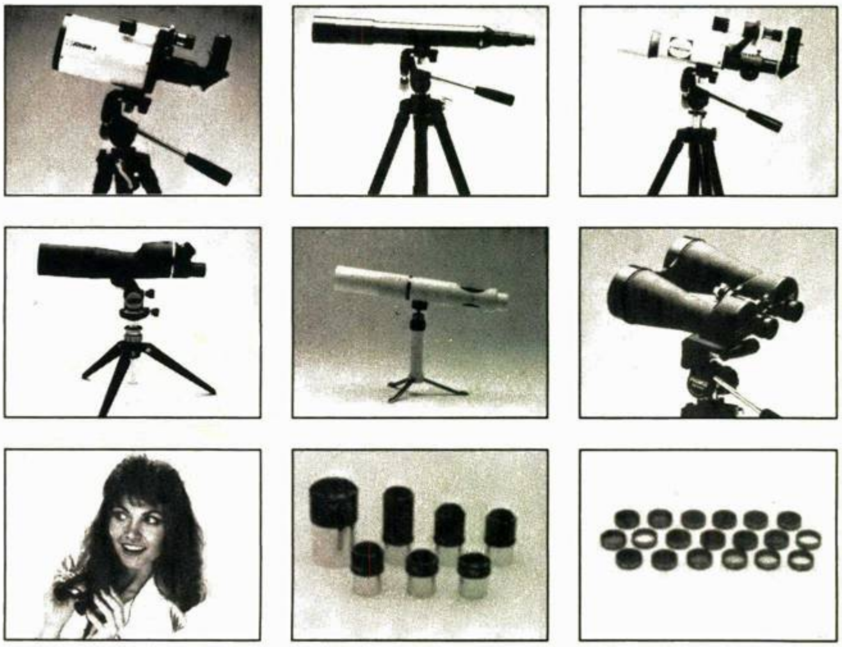

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ASTRONOMY
Forum

In the Glare of the New Moon

The move into space was inevitable. The Earth's resources were dwindling. Energy consumption was increasing at an alarming rate. The virtually unlimited resources, once beyond man's reach, had now been harnessed by man. The exploitation of the last frontier was well under way.

The first artificial satellites were inoffensive, a nuisance only to the lost art of Earth-based deep-sky astrophotography. The satellites were actually a treat to those new to astronomy. The sight of a fast-moving, sometimes blinking point of light would draw excited shouts from observers at the now rare gatherings once known as star parties. But the satellites were no longer inoffensive.

It had been years since the conditions in the season of eclipses had been this ideal. The Moon was only a few days old and had already set; the latest satellite was about to swing into Earth's shadow, grow fainter, and then disappear. The weather was cooperating: the autumn night was clear. The observer arrived at his site in the late evening, several hours before eclipse time.

Timing and planning were critical to his observing session. He had rehearsed the procedure for setting up his old telescope and collimating the optics several times. He carefully packed and organized the components so he wouldn't lose or misplace parts. He took his time assembling the little-used instrument, paying attention to the smallest detail. An error could cost several minutes of darkness. The eyepieces and charts were neatly organized on a small table so he wouldn't be confused in the unfamiliar dark. He reviewed the objects he planned to observe and their locations: the Andromeda Galaxy, the Double Cluster, and a few of the brighter nebulae. He tried to keep the list down to a minimum, though he never managed to work through the entire schedule.

In the grassy field he sat patiently, waiting for ingress. He wore dark sunglasses to ensure his eyes would be dark adapted by eclipse time. The sky was darkening — the eclipse was entering the umbral stage. He pointed the telescope in the direction of the Andromeda Galaxy. Being out of practice, he took some time to regain the feel of the telescope and to find the galaxy. The field of the low-power, wide-angle eyepiece was still quite bright and obscured all but the core of the galaxy. As the eclipse neared totality the Andromeda Galaxy shone in all its glory. The sky darkened to a blackness few people in his time ever saw. His children would never know the sky as he had known it in his youth. A heritage lost.

Every observer in the Western Hemisphere (when he wasn't under clouds) shared the moments of darkness. Some banded together in groups to behold the sky as it once was — glittering with stars. He, however, preferred to be alone. For him these brief moments of observing had become a solitary pastime.

He found it difficult to express the feelings he experienced when observing a faint, elusive object to people who had no conception of what it is like to look through a telescope or at the stars. He stopped trying. In observing groups he found too many distractions, too many questions, too much chatter. Without enough telescopes to go around serious observing was impossible. He lost his patience with the curiosity seekers. These minutes were far too precious to waste.

There was, of course, a great deal of opposition to the deployment of this satellite from the scientific community. But set against a world starved for energy, the scientists didn't stand a chance. Except for a few hours in the spring and fall the large professional observatories — with billions of dollars of equipment — were severely handicapped if not rendered useless by the light-polluted sky. The telescopes themselves, once symbols of achievement, fell victim to the same technology that bore them.

Never before had he observed the galaxy for so long. The delicate detail the telescope revealed held him mesmerized. He recalled a time, long ago, when he actually identified several globular clusters in the galaxy, traced the path of the obscuring dust, and even examined the hydrogen clouds in the spiral arms with the aid of filters designed to block light pollution.

Light pollution. The thought brought him out of his reverie. The field was brightening. He had spent the entire

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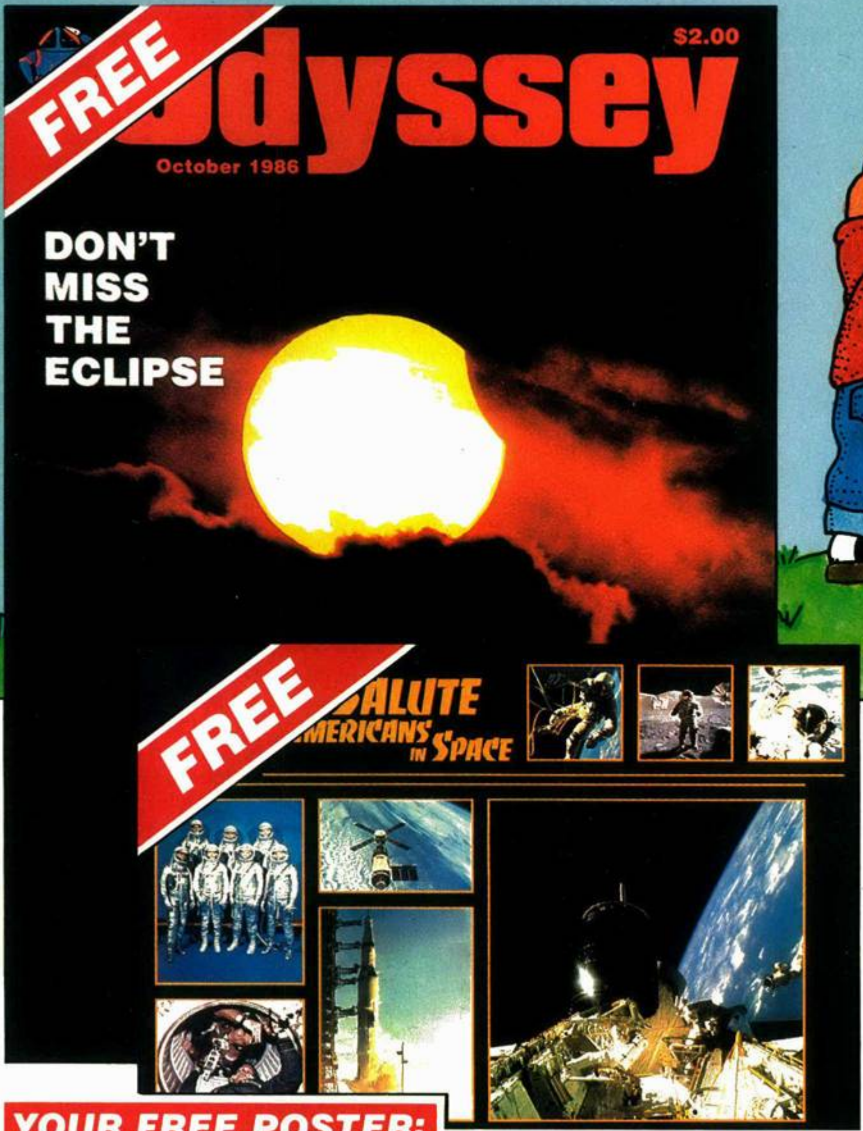

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observing window on one object. There was so much he wanted to see but so little time. In a matter of minutes the field was so bright all but the brightest portions of the galaxy were blotted out.

He looked up from the eyepiece and watched the new "moon" move out of Earth's shadow: the great, glowing rectangle of the satellite was awe-inspiring and, even after all of these years, still an unnatural site. He could easily distinguish detail in the enormous solar-powered satellite suspended in the sky in near-geostationary orbit. Although smaller in apparent size than the Moon, the satellite was brighter, so much brighter. Soon the Milky Way was lost and only the brightest stars could penetrate the glare. The satellite turned night into day. He turned away from its intense light.

The once active observer sat uncomfortably in his armchair a few nights later. Although the sky was clear, both moons were bright. The only way for him to observe the wonders of deep space would be to bring out the old, priceless books and magazines adorned with astrophotos. To this day he is still amazed he took these wonders and the ability to observe them for granted. Very carefully he leafed through precious pages. With a great deal of nostalgia he reread the deep-sky observing articles and reports of the amateur conventions. That was another world.

Peter Ceravolo
Edmonton, Alberta

An Observer's Midsummer Night's Dream

The day had been breezy with puffs of fleecy clouds hurrying across a hard blue English sky. With the promise of a clear evening to follow, Chris Walker, Malcolm Johnson, and I drove over to the Sixth Form College in Stockton-on-Tees in northern England, where Chris was giving an illustrated talk on astrophotography to the members of the Cleveland [County] Astronomical Society.

Stepping outside afterwards we noted with despair that the sky was an awful sodium yellow, so typical of cloudy, urban nights. However, by the time we had returned to Chris' home at Neasham, the clouds had broken up, leaving large patches of clear sky. We were all looking forward to using Chris' pride and joy: a 17.5-inch Newtonian reflector.

With the run-off roof of his observatory trundled back on its rails, we pondered which celestial showpiece to examine first. By common agreement we looked at the planet Jupiter, which had dominated the southern sky throughout the summer, shining at magnitude −2.4. The seeing was disappointingly poor because the flattened, cream-colored disk shimmered around the limb, but we could make out the North and South Equatorial Belts as well as the North and South Temperate Belts. During moments of steadier seeing some finer detail could be seen in the Newtonian and through the 4-inch refractor strapped on the tube of the 17.5-inch scope. Because the smaller aperture makes it less vulnerable to poor seeing, the detail was firmer in the smaller scope than in the Newtonian.

Globular clusters are always enhanced by a larger aperture, and high above our heads between the stars Eta (η) and Zeta (ζ) Herculis was M-13, the best northern example of this class of object. Fired with tingling excitement we trained the 17.5-inch on the huge swarm of packed stars that filled the field of view at a magnification of 222x. Smaller instruments will resolve M-13, but the 17.5-inch telescope provided one of the most impressive sights in the heavens. In fact, poor Malcolm was so shocked when he saw the cluster through the large reflector for the first time that he fell off the stepladder used when observing near the zenith with this instrument.

I tracked down another globuar, M-2 in Aquarius. This cluster was another glorious sight, completely resolved by the 17.5-inch. The same thing happened with M-15, which appears in the neighboring constellation of Pegasus.

One of our favorite deep-sky objects is M-57, the Ring Nebula in Lyra. This planetary nebula always reminds me of a "polo-mint," and it was really bright in the Newtonian this night. We have yet to see its central star, but this isn't for lack of trying. We are hoping to see it through the 30-inch reflector at the Amateur Astronomy Centre in Todmorden, Lancashire.

In the small constellation of Vulpecula lies the superb planetary, the Dumbbell Nebula, which was our next target. Shining at about magnitude 8, the nebula does somewhat resemble a dumbbell in a small scope, but the 17.5-inch showed it as a disk.

By this time a conspicuous glow in

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the eastern sky (even greater than that provided by industrial Teeside) signaled the arrival of the Moon, which was nearing Last Quarter phase. We were prevented from observing it straight-away because an unused brickworks partly blocks the sky at the 17.5-inch site. Salvation was provided by Chris' portable 3.5-inch rich-field telescope, which we set up on a grassy hillock about 150 yards from his home. We were rewarded with a pleasing view of the Moon close to the Pleiades in Taurus. The latter was a grand spectacle in the RFT with many more than the six or seven naked-eye stars visible.

Taking advantage of the fact that the constellation Andromeda was high in the sky, Malcolm trained the telescope on M-31. Even with the wide field provided by the RFT, the spiral arms extended across the field of view with a bright condensed nucleus in the center. Returning to the 17.5-inch we enjoyed magnificent views of the spiral's satellite galaxies M-32 and NGC-205.

At long last the Moon ascended above the brickworks and was within range of the large reflector. I enjoy the Moon at its Last Quarter phase more than at First Quarter. Perhaps this is because the Last Quarter is best seen during the approach of dawn and is less frequently observed than the First Quarter on more readily accessible evenings. During the small hours the seeing is often best, and this morning was no exception: the resolving power of the 17.5-inch could be fully exploited. We used a 32mm Erfle eyepiece with a magnification of 60x to fit the Moon nicely into the field of view.

Chris uttered a gasp of amazement as he looked through the eyepiece, and when it was my turn I found out why. I have gazed upon the jumbled surface of our nearest neighbor many times, but never before had I seen it like this! The rock-steady image had an incredible crispness and the complexity of detail in formations like the Apennine Mountains was beyond comprehension. We all felt as if we were in a space capsule orbiting the Moon — a tremendous, awe-inspiring thrill indeed!

Switching to higher magnifications we were able to wander at will among the highlighted regions on the lunar terminator, which were undergoing sunset. I was able to pick out a multitude of tiny craterlets on the floor of the magnificent crater, Clavius, near the Moon's south polar region. Directly to its north, part of the floor of a subdued Tycho was in shadow. The famous "Straight Wall" on the southeastern edge of Mare Nubium appeared as a thin bright line, as it always does at Last Quarter. (At First Quarter it appears as a thin, dark line, but it is really a slope rather than a wall.)

East of the Straight Wall is the peculiar formation Thebit, a combination of three successively smaller, overlapping craters that never fails to catch my eye when near the terminator. Moving north, Arzachel, Alphonsus, and Ptolemaeus were all filled with incredible detail. Malcolm's favorite crater is Copernicus, located in the northwest quadrant near the equator, and he was able to pick out the intricate terracing on its internal walls.

Close to Copernicus are some delicate crater chains that many believe were formed by the same impact that created their large neighbor. The excellent seeing permitted us to pick out the individual craterlets at 222x. On the smooth gray floor of Mare Imbrium, stygian shadows were cast by the isolated peaks, Pico and Piton. These shadows, when at their longest, provide a mystical semblance of cathedral spires!

Dawn was well under way, and it was time to cap the optics of our large telescope, its night's work very well done. It had been an observing session never to be forgotten — an almost dreamlike experience in retrospect — but an amateur astronomer's memories are composed of nights like these.

David L. Graham
Richmond, North Yorkshire, England

Starlight Reflected in a Diamond

As the Sun set, it dyed the blue sky shades of red, orange, yellow, and violet. Inside a diamond was a smaller sky, a crystal sky, and here too the Sun was setting. Yet in this carbon atmosphere the varied angles and densities through which the sunlight flowed further scrambled the colors, and with this carbon accent the sunset sparkled.

The sunset was also sparkling in the eyes of the woman who carried that diamond on her finger. She stood on top of a mountain and gazed over lower mountains and hills rolling downward into desert plains. She was watching the colors and the clouds flow through the sky and the patterns of light and shadow flow across the land. The air-twisted light flowed into her eyes and was curved again by her lenses to ignite within her brain a third version of the sunset — colored by both light and delight.

As the sunset faded, the woman turned and walked into the observatory. Her footsteps echoed under the huge dome as she walked through the dimness past a silent computer, past the telescope, and sat down at a control panel. She turned a key and the panel bloomed with brightly colored lights. She pressed one of those lights, initiating much vaster and more powerful forces.

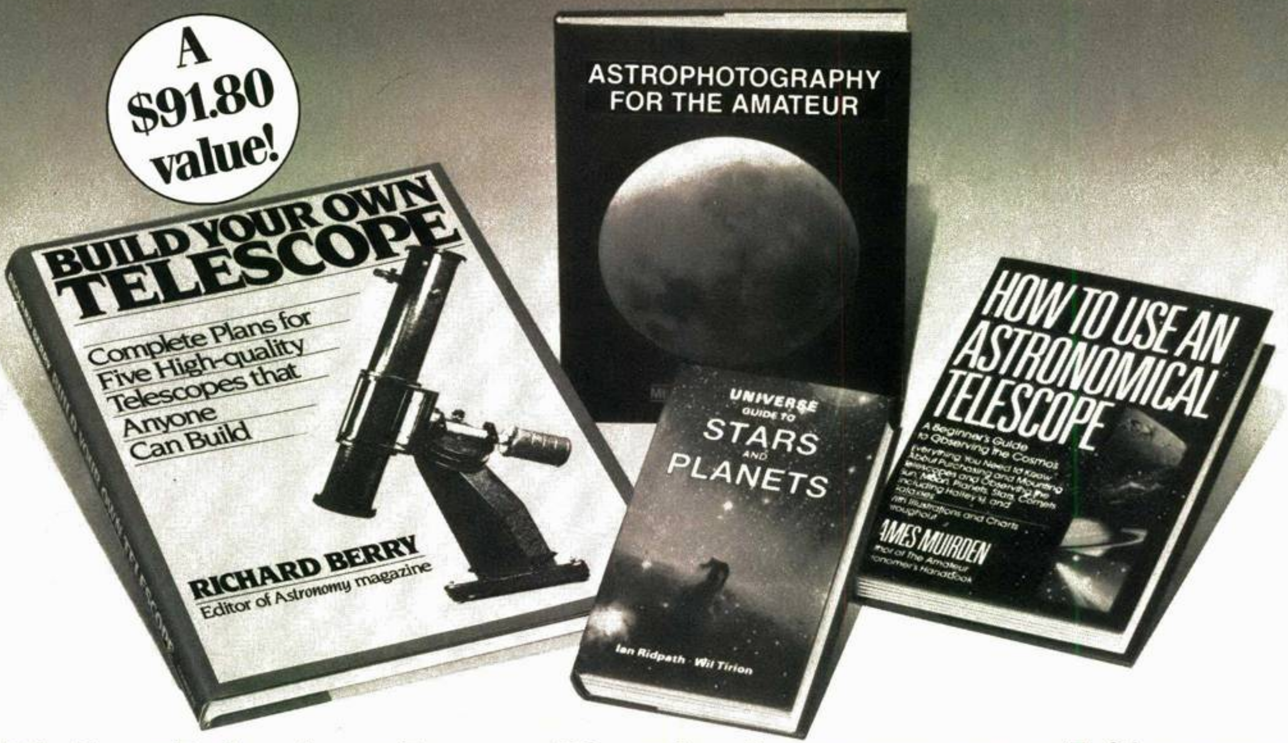
Accompanied by the sound of a throbbing engine, the eyelid of the dome slowly opened to the sky. Another engine poured out tons of power to turn the dome itself, which rotated past the sunset and almost stopped at one point of the sky; the telescope followed to the same point and almost stopped, except for a tiny continuing motion that would keep the telescope aligned to that point all night. Synchronizing the telescope to the movements of the turning planet, the circling of which was geared to the larger circles of the solar system that in turn formed the larger whorls of the Galaxy, the woman touched the Galaxy's luminous fingerprint.

Through the diamond on her finger she was also touching the larger forces at work inside the Earth. The diamond contained the pressures that built mountains and forced earthquakes, that melted rock and squeezed it upward through the crust and fired it from volcanoes. These pressures were sometimes blocked below the Earth's surface, which only pressed the magma harder and harder until it was fiercely hot enough to break its molecular structure and press that structure into a new form. The diamond was pure carbon sieved from the flowing rock and compressed until the atoms locked into a tight recurring pattern: each atom bound to its four nearest neighbors in a tetrahedral arrangement.

Geometrically this pattern was quite simple. Yet like the geometrically simple markings on a cuneiform tablet, this pattern contained a meaning far more complex and profound. In the untranslatable hieroglyphics of this crystal the ability of a universe to order itself was written.

As the colors of the sunset faded and disappeared in the darkening sky, the stars appeared. Through the deepening blue the brightest stars emerged first. Others slowly followed until a dozen stars were emerging from the twilight each minute, then two dozen, and then the sky was black and filled with thousands of stars gleaming sharply in the clear mountain air, sparkling white and red, yellow and blue. Sparkling like diamonds.

These diamonds too had crystallized out of formlessness, out of crude, flowing matter, out of fierce pressure and temperature. Each had been squeezed from a cloud of gas that had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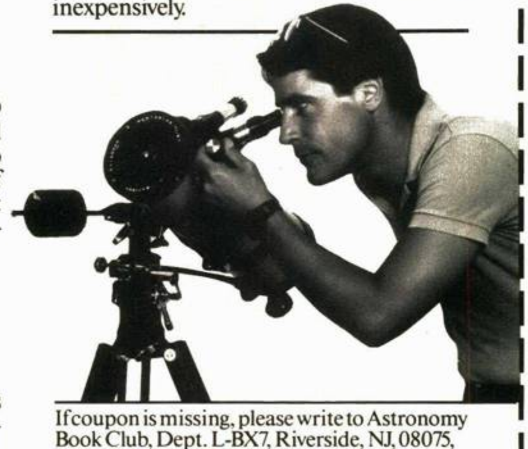

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flowed through space and become trapped within its own gravity, collapsing inward and becoming denser and hotter until its atoms collided fiercely enough to break their atomic structure and fuse into heavier atoms. The bursts of light from each fusion merged into a tide of light flowing outward, a blade of light that eventually cut away the tough, splotchy cloud and left a geometrically perfect star gleaming in space.

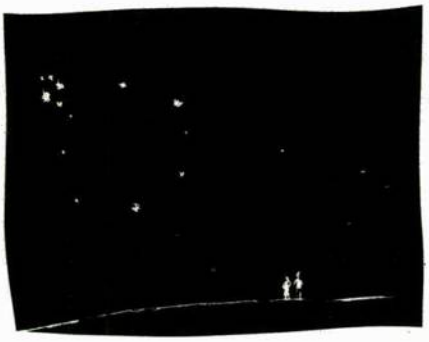
The diamond on the woman's finger was a continuation of the same process that formed the stars gleaming above the observatory. This process had been continuing for billions of years, ever since it was unleashed by the Big Bang. And toward the earliest traces of that process the woman was aiming the telescope. Past the planets twinkling with today, past the stars and nebulae of our Galaxy, past the galaxies glowing from the eons, she aimed the telescope at a young galaxy crystallizing from the chaos of the Big Bang.

From the first instant of the Big Bang the universe was rich in forces able to generate order. Some of those forces were at work immediately; others would have to wait ages until the Big Bang sorted itself out before they could take effect. Eventually these elementary forces would combine to form more sophisticated ordering forces.

In the Big Bang matter swarmed and collided intensely enough to trigger the strong nuclear force that bound particles into atomic nuclei. As the Big Bang expanded, the swarming diffused enough for the electromagnetic force to bind electrons into orbit around the nuclei and form atoms. Gravity was also binding the swarm into the larger forms of galaxies with quasar hearts and star veins winding throughout. In the stars atoms were again smashed together hard enough to bind them into heavier elements, including carbon. These elements eventually became abundant and were scattered into space by dying stars and, as new stars formed out of clouds of those elements, the clouds could also crystallize into planets.

As gravity flowed from inside a planet and sunlight flowed from outside, they merged their energies to work upon the planet's surface. Matter was sorted and mixed, piled and pressured into new forms: rocks and mountains, raindrops and oceans, snowflakes and glaciers. Thousands of large and small processes brought matter together in new ways and let the electromagnetic force bind atoms into substances, into simple molecules repeated over and over or into collages of dozens of kinds of molecules.

The atom most capable of forming complex molecules was carbon. Each carbon atom could bind to four other atoms at once and bind firmly enough to maintain a complex form, yet not too firmly that a huge amount of energy would be required to break the atoms apart. Brewed by ocean waves and surf, by wind and lightning, carbon atoms grew into long, intricate molecules with forms that sometimes gave them a special function in the society of carbon molecules, such as being able to bind molecules together or split them apart, being able to carry a large amount of energy or information, or being able to form a wall or a sphere. After ages of random combinations the right molecules came together and merged their tiny abilities into a greater ability called life.



Life's elaboration eventually produced societies in which each animal, like a molecule in a cell, performed a special role to maintain the whole. Such cooperation between individual animals required a new kind of binding force, not a physical force because the animals were not physically connected like molecules in a cell, but a force that would hold them together as strongly as the atoms in a diamond are bound.

This strange, difficult new force was feelings, and feelings pulsed with different flavors: they would bind animals into packs and societies, into families and nations. Because the continuation of form depended most upon bringing male and female together, this bond worked most strongly between them.

After glancing at her glowing watch, the woman rose from the console. She walked beneath the telescope and passed the computer, which now hummed with activity.

She reached the door, stepped outside, and stood gazing at the stars and the vague shapes protruding from the darkness below. In that darkness she was looking for a light winding its way up the mountain.

Then the clear darkness divulged the car. A form emerged from it, and amid thousands of stars and the gravity guiding them, the two humans met and embraced and kissed, and each verified with three words that the emotional gravity holding them together was still working.

Holding hands, they walked up the steps and into the observatory. They passed the telescope and its photographic bull's eye, into which the star-fired arrows were flowing. That photographic plate had started out as empty and black as the universe had once been, but with the passing minutes of a long exposure order was emerging from the blackness. First the sharp, white dots of foreground stars appeared and then the vaguer white of a galaxy slowly followed.

Within the woman too a form was slowly taking shape. Her womb was a photographic plate, the chemicals of which had been activated to form the image of herself. Through a long exposure lasting many months this plate would collect bits of information from a past as vast as the eons from which quasars shine and from the genes containing the whole evolution of life on Earth.

The light flowing into the telescope above the woman was also flowing into the lens upon her finger. Through the opening in the observatory dome the starlight poured from a hundred stars visible to her and from countless stars her eyes couldn't register. It came from the stars nearest the Sun and from stars hundreds of light-years away. It came from nebulae glowing with the light of newborn stars, it came from stars 5 billion years old, it came from stars that had collapsed into white dwarfs and neutron stars. It came from galaxies still forming from the Big Bang. Light from the entire history of the universe was flowing into her diamond, being folded this way and that and emerging again in the faintest sparkles.

Her diamond contained the whole universe, not just its light but also its structure. Its atomic nuclei contained the energy of the Big Bang. Its carbon atoms contained the burning of the stars. Its crystalline form contained the geological forces of Earth. Its cut and polished form contained the evolution of life into complex thoughts and feelings, into a form of carbon that could choose as its symbol of continuation a form of carbon both strong and beautiful.

The diamond was the pure element of life, the element that had turned the universe's most amazing adventure into order. The diamond embodied the whole mystery of form in the universe. In the starlight flashing from it, as in the starlight entering the crystal eyes of humans and being folded into consciousness, that mystery was proclaiming itself as clearly as it had in the flash of the Big Bang.

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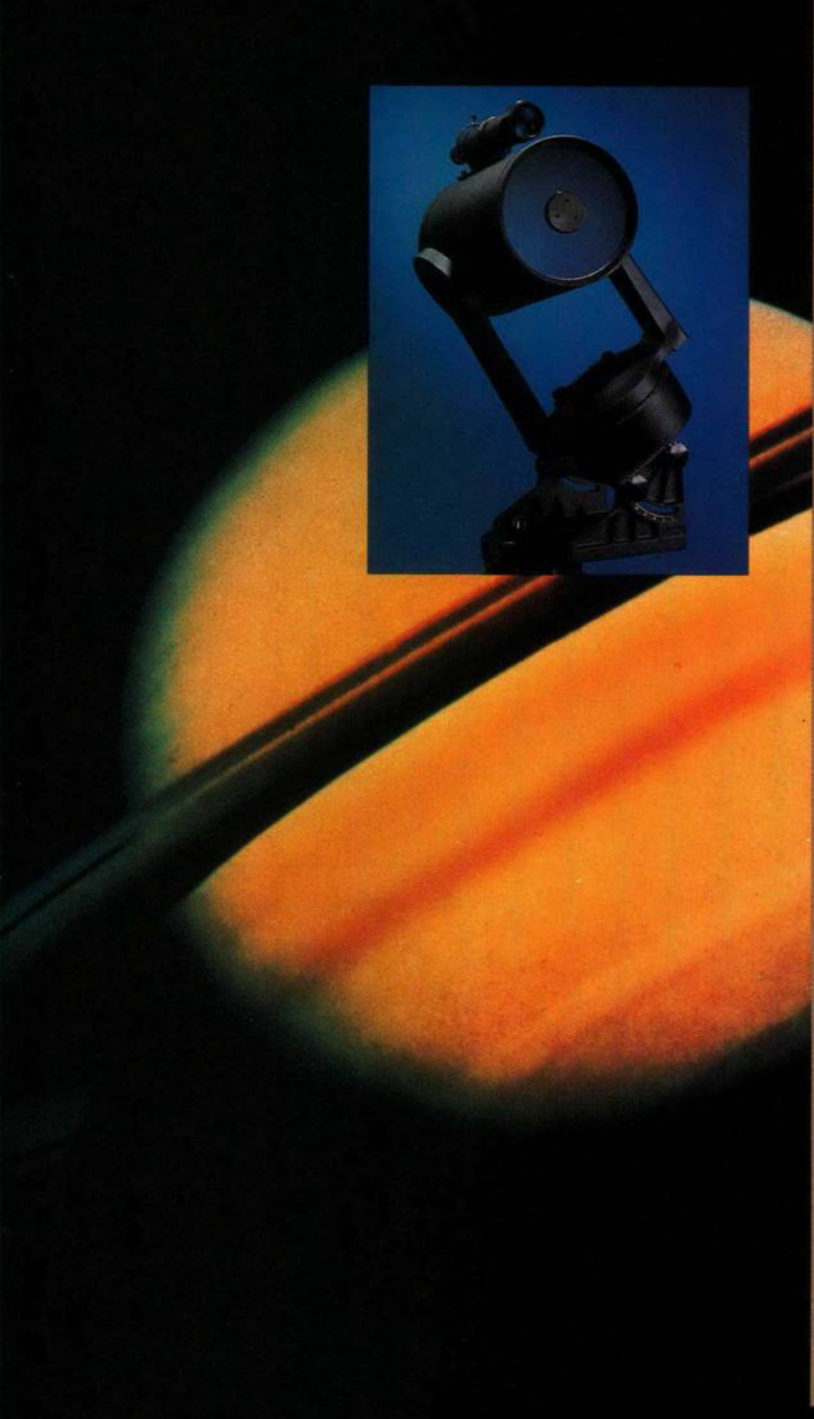

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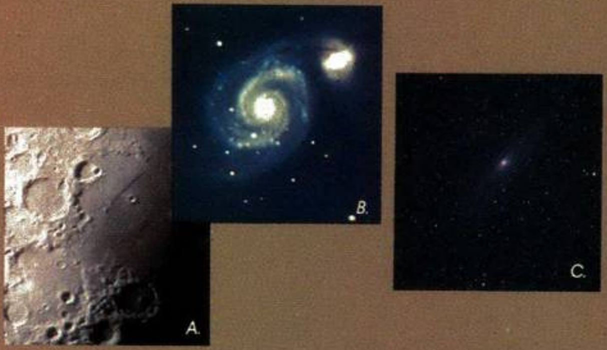
Best of all, the American built 8001 comes from a company with over 133 years of experience in optical excellence and is backed by a limited lifetime warranty.

If you're considering buying a high quality 8 inch telescope, look into the revolutionary new 8001. And see why it's the telescope system that's light years ahead of the competition.



A. Lunar Craters photographed through the Bausch & Lomb 8" Schmidt/Cassegrain using eyepiece projection at an E.F.L. of over 32,000 mm!

B. Galaxy M-51 taken by Dr. Stephen Kent of Harvard University with the Bausch & Lomb 8" Schmidt/Cassegrain and a C.C.D. Exposure time — 10 minutes!

C. Galaxy M-31 taken by Jeff Peronto using a 300mm lens mounted piggyback on the Bausch & Lomb 8" Schmidt/Cassegrain. This photo is a 16 minute unguided exposure illustrating the superior accuracy of the Bausch & Lomb drive system.

When it comes to resolving Saturn's Cassini's Division, the New 8001 runs rings around the competition.

Contact your nearest Bausch & Lomb dealer, or contact us direct at: Bausch & Lomb Astronomical Telescopes 135 Prestige Park Circle • East Hartford, CT 06108 • (203) 282-0768

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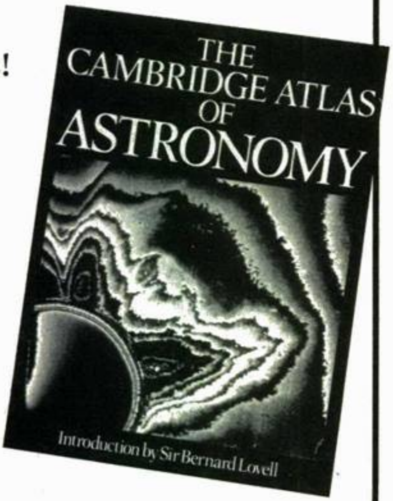
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Introduction by Sir Bernard Lovell

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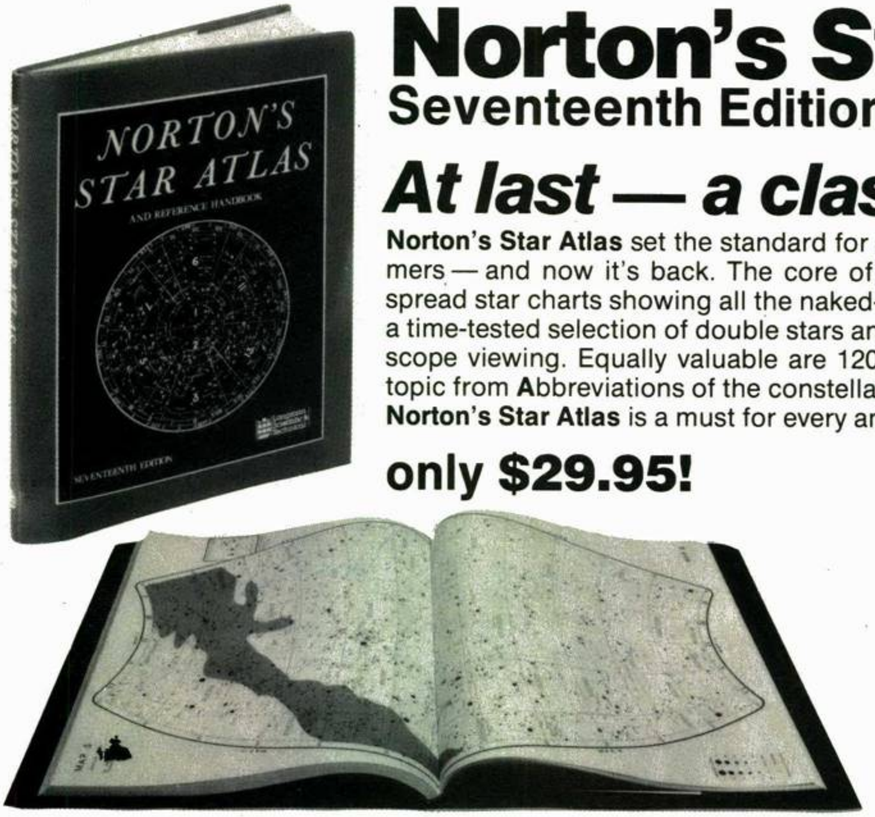

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Includes:

- AC/DC quartz drive
- 8x50 illuminated polar reticle finderscope
- 26mm Super Plossl eyepiece
- 9.7mm Super Plossl eyepiece
- Piggyback camera mount
- Field tripod & wedge
- Lifetime warranty, and more!

Meade 2080 LX-3 Accessories

#36 Remote control box	$89
#38 Declination Motor	$89
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8" Solar filter	$239
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2" Star diagonal	$189
T-adapter	$35
Rotary eyepiece holder	$119
Widefield adapter system	$129
Off-axis guider system	$159
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Meade DS 16A $1849
16" Deep space reflector for serious space viewing and astrophotography. Shipping truck freight collect.

Meade DS 10A $929
10" Deep space f/4.5 reflector. Includes 25mm eyepiece, focuser, pedestal mount, setting circles, motor drive, and lifetime warranty.

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#43 RA Drive Corrector AC/DC	$89
#55 Manual Declination Control	$59
Dust Cover for 10"	$24
Dust Cover for 16"	$32

Meade 8800 $829
8" f/4.5 Newtonian reflector for incredible deep space viewing and astrophotography. Includes features and accessories described above under 6600.

Meade 6600 $599
Compact 6" Newtonian reflector. Includes two eyepieces, 6x30mm finder, professional series equatorial mount with slow motion controls, metal tube assembly, dust cover, altitude & azimuth fine adjustments, setting circles, and lifetime warranty.

Meade 2120 LX-3 $2349
With MCSO. 10" system is 56% brighter than an 8" system, for improved viewing and astrophotography capabilities. Includes:

- Equatorial wedge
- Field tripod
- 26mm Super Plossl Eyepiece
- 9.7mm Super Plossl Eyepiece
- AC/DC quartz drive
- 8x50 illuminated polar reticle finderscope
- Piggyback camera mount
- Lifetime warranty, and more!

Meade 2120 GEM with MCSO $1949
10" Schmidt-Cassegrain with German-type equatorial mount. Incorporates worm-gear controls on both axes, and optional computer control system.

Accessories for the 2120

10" Dew Shield	$99
#1402 Tube balance system	$99

Meade 2080 GEM $879
8" Schmidt-Cassegrain with German-type equatorial mount incorporates worm-gear controls on both axes. Optional computer control system.

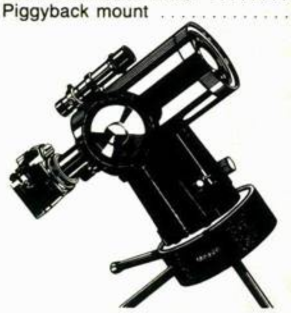
2080 GEM with MCSO $995

Meade 2045 LX-3 $779
4" Schmidt-Cassegrain with quartz drive, dual motor system, AC/DC operation. State-of-the-art electronics for sharp, brilliant images.

Meade 2045 $579
Compact 4" Schmidt-Cassegrain telescope, spotting scope, and 1000mm lens, all-in-one. Includes clock drive, metal-clad case, 5x24mm finder, 40x and 111x eyepieces, coated optics, tabletop tripod, lifetime warranty, and more.

Accessories for the 2045

4" Dew Shield	$49
#38A Declination motor	$89
Piggyback mount	$19



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6.4mm	$89
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12.4mm	$89
15mm	$89
20mm	$89
26mm	$89
32mm	$115
40mm	$115
56mm/2"	$199

Meade Super Wide Angle Eyepieces

13.8	$139
18	$149
24.5	$169
32mm/2"	$249
40mm/2"	$319

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4.7	$169
6.7	$199
8.8 1.25/2"	$239
14 1.25/2"	$279

Meade 1.25" Barlow Lenses

2x	$89
2.8x	$89

Meade Accessories

1¼" Color filters	$15
#908 Nebula filter	$69
#911 Nebula filter	$119
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Accessory shelf for 8"	$29
#419 Illuminated reticle	$89
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LUMICON FOR HIGH PERFORMANCE

ASTROPHOTO OF THE MONTH

Spiral Galaxy M-99 (NGC 4254) in Coma Berenices. Spiral structure detail can be seen visually for this 10th magnitude galaxy. 40 minute photo by Dr. Jack Marling using hypered 2415 film, 24" f/6 telescope and LUMICON Giant EASY-GUIDER.

20mm NAGLER

Also new 12mm & 16mm NAGLERS

TELE VUE™ EYEPIECES USE THE BEST!!

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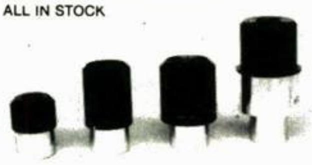

Renaissance 4" f/5.5. Telescope	$1395
7.4, 10.4, 13, 17, 21, 26mm Plossl, 50°	$89
1.8X or 2.5X Tele Vue Barlow Lens	$89
32mm Plossl, widest true field in 1¼"	$109
55mm 2" Plossl, widest possible field	$190
15mm Wide-Field, 1¼" eyepiece, 65°	$129
19mm Wide-Field, 1¼" eyepiece, 85°	$139
24mm Wide-Field, "superb," 65°	$159
32mm Wide-Field, 2" eyepiece, 65°	$229
40mm Wide-Field, "awesome," 65°	$289
4.8mm Nagler, 82° field	$149
7mm Nagler, 1¼" eyepiece, 82° field	$185
9mm Nagler, 82° field, "the best"	$219
11mm Nagler, 82° field, 1¼" or 2"	$235
13mm Nagler, 82° field, 1¼" or 2"	$249
12mm Nagler, type II, 82°, 1¼"/2"	$249
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Upgrade to 48mm filters! All are multicoated

UV, Green, Yellow, Orange, Red	**$18 each**
48mm H-Alpha Pass (640nm cut-off)	$35
48mm Minus Violet (420nm cut-off)	$29
48mm High perform blue, 90% trans	$35
Central Star Filter (blue tri-color) 340-470nm bandpass	$35
UV-370 U-Band, 320-420nm bandpass	$35
48mm Polarizer (2 make variable density)	$18
Set 9 ea. 48mm filters ($259 list)	$195
2"/1¼" adapter threaded for 48mm filters	$20

H-ALPHA PASS FILTER

Yields spectacular contrast gains in B&W photography with telephoto lenses. Yields pinpoint star images. Superb with hypered 2415. For color, use the Minus Violet (MV) Filter.

Specify Lens Size	H-Alpha	(MV)
46, 48, 49mm	$35.00	$29.00
52, 55, 58, 62mm	$45.00	$35.00
67, 72, 77mm	$52.00	$45.00
82mm	$55.00	

Hypered 2415 film, 36 exp . . . $10.95 . . . 3/$29

NEW! ENHANCED SILVER DIAGONAL MIRRORS BOOST TELESCOPE PERFORMANCE

LUMICON 1.3" & 2.1" enhanced silver diagonal mirrors & 1¼" star diagonal.
The new LUMICON diagonal mirrors have a special enhanced silver coating with a protective overcoating for long life. Visible reflectivity is 98-99% compared to 86-89% for standard aluminum coated mirrors. The extra 10-12% transmission is like adding an inch of aperture! The substrate is fine annealed Pyrex flat to 1/8 wave

1.32"	**$29.95**	1.52"	**$34.50**	1.83"	**$39.50**
2.14"	**$49.50**	2.60"	**$65.00**	3.10"	**$89.50**
4.25"	**$149.50**				

ENHANCED SILVER STAR DIAGONAL

90° star diagonals with above enhanced silver mirrors in a CNC machined black anodized aluminum body. Performance far exceeds prism diagonals.

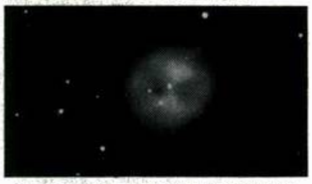
1¼" (1.32" mirror)	$89.50
2" (1.83" mirror)(see photo above)	$145.00

LUMICON FILTERS STOP LIGHT POLLUTION

UHC Filter™

ULTRA HIGH CONTRAST

The **LUMICON UHC FILTER** is specially designed for visual astronomy in areas of severe light pollution or for viewing very faint nebulae at any location. **UHC** stands for **U**ltra **H**igh **C**ontrast and this filter is guaranteed to yield a higher visual contrast on planetary and emission nebulae than any other filter at any price. 24nm visible bandpass, 482-506nm. Transmission = 85-95%.



"I CAN SEE THE OWL NEBULA!"
Tom Kramer saw the Owl Nebula, M-97, for the first time using a LUMICON UHC Filter. He stated, *"I had never seen M-97. . . I attached the UHC Filter and tried again. M-97 was right there. I could not believe it! The UHC Filter should be standard equipment."* **Tom Kramer, Sayville, NY**

For optimum astronomy, use either the **LUMICON DEEP-SKY Filter** or the **LUMICON UHC Filter**

DEEP-SKY FILTER™

The **LUMICON DEEP-SKY FILTER** improves your view of **all** deep-sky objects including galaxies and comets. It removes natural and man-made light pollution and yields 3-6x contrast gain for nebulae and 1-3x contrast gain for clusters and galaxies. It is ideal for **both** visual use and B&W or color photography. This gentle filter yields the most natural view of any LPR filter available today. 90nm visible bandpass. 442-532nm. H-Alpha 656nm transmission = 85-95%. Visible transmission = 90-95%.

	Standard	Premium*
0.96" LUMICON DEEP-SKY Filter threads into most 0.96" eyepieces		$59.50
1¼" LUMICON DEEP-SKY Filter threads into most 1¼" eyepieces		$79.50
48mm LUMICON DEEP-SKY Filter (1.75" aperture), threads into most 2" eyepieces. Also fits LUMICON EASY-GUIDERS		$119.50
2" LUMICON DEEP-SKY Filter (1.5" aperture), threads into most 2" eyepieces. Also has male & female camera T-threads for prime focus photography	$99.50	$119.50
72mm LUMICON Giant DEEP-SKY Filter (62, 67, 77mm adapter, $8)		$299.50
1¼" LUMICON UHC Filter threads into most 1¼" eyepieces	$79.50	$99.50
48mm LUMICON UHC Filter (1.75" aperture) fits most 2" eyepieces	$159.50	$199.50
Set of Both 1¼" **DEEP-SKY** and **UHC Filters** (Save 11%)		$159.50
LUMICON H-BETA Line Filter (9mm bandpass at 486nm). For the California Nebula, Horsehead Nebula, and other extremely faint nebulae.	1¼" $89.50	48mm $189.50
Oxygen-III Filter for very faint planetary and diffuse nebulae, 11nm bandpass at 496nm and 501nm 0-III lines	1¼" $99.50,	48mm $199.50
Telephoto lens adapter for 2" or 48mm filter. Select 46, 49, 52, 55, 58mm		$6.95
Universal adapter for 1¼" filters. Adapts the 1¼" filters to any 1¼" eyepiece		$16.00
Universal adapter for 48mm or 2" filters. Allows use of any 1¼" eyepiece		$20.00

**Premium filters are selected best of the lot and typically have 5-10% higher transmission. Not always available. Include individually measured transmission data.*

DEEP-SKY ASTROPHOTOGRAPHY

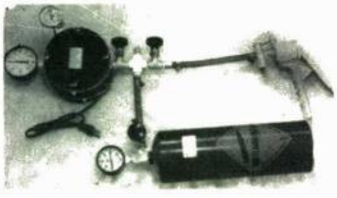
FILM HYPERSENSITIZATION KITS†

LUMICON HYPER-KITS™ yield 3-15X film speed gain in long exposures. They are safe & simple to use. Easy HYPER-KIT includes a chamber with all controls and fittings, thermometer, a refillable cylinder of non-flammable forming gas & hand-operated vacuum pump.

U.S. Patent 4,473,636

MAKE YOUR OWN HYPERED FILM

MODEL 300 HYPER-KIT sensitizes any 35mm film in hours. Best for 2415. Achieves highest possible film speeds $295.00



MODEL 600 HYPER-KIT [See Photo] Like the Model 300, but also sensitizes 120/220 larger format film and small glass plates $350.00

MODEL 1200 HYPER-KIT is for 4X5" plates and film up to 5X7". Has 2 gas cylinders and includes temperature controller . . $595.00

Temperature controller for any HYPER-KIT $59.50

Electric Vacuum Pump, Model R-10 $280.00

GUIDE OFF-AXIS FOR LOVELY ASTROPHOTOS

All **LUMICON EASY-GUIDER™** off-axis guiders† have both radial and 360° rotational adjustments for 5X eaiser guide-star selection, use 48mm filters, 360° camera rotation, large prisms fo bright guide-starts. *Specify Camera and Telescope type.*
U.S. Patent # 4,448,500

NEWTONIAN EASY-GUIDER™

Full aperature. Installs in secs. Specify 2" or 1¼".

NEWTONIAN EASY-GUIDER	$169.50
3X Relay Diagonal (see photo)	$79.50
Illuminated reticle eyepiece system	$89.50
Guider for Hasselblad **$350,** Mamiya 645	**$199**

CASSEGRAIN EASY-GUIDER™

For C-8, Meade 2080, Dynamax-8. Includes 50mm achromatic lens for f/5.8 operation-3X shorter exposures! **Superb rich field viewing, too!**

CASSEGRAIN EASY-GUIDER	$225.00
Adapter for Hasselblad **$185,** Mamiya 645	**$159**

GIANT EASY-GUIDER™

For Celestron-11, C-14, and the 10" Meade 2120. Includes 80mm clear aperture achromatic lens for edge-to-edge illumination & pin-point star images. F-ratio adjustable f/4-f/11. **Also yields unmatched Rich-Field viewing.**

GIANT EASY-GUIDER	$395.00
48mm DEEP-SKY Filter ordered with any EASY-GUIDER (SAVE $20)	**add $99.95**
Adapter for Hasselblad **$195,** Mamiya 645	**$96**

WHAT DO YOU NEED?

1. Illuminated reticle eyepiece **$89.50**
Lumicon 12mm eyepiece system has adjustable L.E.D. illumination, dual crosslines, battery pack.
2. Cable release for long exposures . . **$9.95**

3. **LUMICON Quartz Drive Corrector $219**
Dual-axis drive corrector is essential for astrophotography and/or field use of your telescope. 40Hz/80Hz variable output controls telescope drive. 60Hz Quartz reference ±12VDC Declination control output. Both 110VAC and 12VDC input for home or field use. Declination reverse switch for Newtonians.
Declination motor (state telescope) . . $70
NEW Deluxe Digital Qtz. Drive Correc. **$298**

HYPERSENSITIZED FILM

LUMICON Hypersensitized film is essential for good deep-sky astrophotography. Deduct 10% for 3 or more rolls (mixed o.k.).

Film Type, 35mm	Exposures	Price
2415, Ultra-fine B&W, red sens.	36	$10.95
SR1600, fastest of all, color neg	24	$12.95
Konica SR200, fine grain color neg	12	$9.95
3M 1000, fastest slide film	20	$12.95
Fujichrome RD100, fine grain slide	24	$12.95
5072, color slides from neg	36	$6.95
D-19 B&W Developer	1 gal.	$6.95

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NEW! Meade 2120/GEM and 2080/GEM

Meade Authorized Dealer

Meade® TELESCOPES AT LUMICON

MEADE 2080/LX3 w/MCSO $1685

#712 Dew shield (8") and accessory tray ($140 list)	**add $89**

MEADE 2120/LX3 w/MCSO $2590

Accessory shelf for field tripod ($40 list)	**$32**
#710 dew shield (10") Essential! ($140 list)	**$98**
#36 dual-axis drive corrector control box ($150 list)	**$99**
#38 declination motor and clutch ($150 list)	**$99**
LUMICON Giant EASY-GUIDER/Rich-Field viewer for f/4-f/10 operation (state camera)	**$395**

2080/LX3

$1685
2080/LX3
W/MCSO

NEW! Quartz Drive Meade 2080/LX3

The Meade 2080/LX3 with built-in quartz electronic drive system is positively the highest performance 8" Schmidt-Cassegrain telescope system available today.

2120/LX3 10'' System w/MCSO $2590

The 10" Meade 2120/LX3 collects 56% more light than an 8" telescope for significantly improved viewing and astrophotography. It has all the features of the 2080/LX3 (see Meade ads in this magazine for full list of features.)

4'' MEADE 2045 w/table tripod $598

NEW! Meade 2045/LX3 w/quartz drive	**$795**

IN STOCK!

NEW!
2045/LX3

Meade Model 2045 — Advanced engineering and superb optical performance in a beautiful ultraportable system.

FEATURES OF THE MEADE 2045

- ★ 4" f/10 Schmidt-Cassegrain optics, F=1000mm
- ★ Motor drive for automatic tracking, 110 VAC input
- ★ **LX3:** quartz-controlled elec. drive, 12VDC or 110VAC input
- ★ High transmission coatings on front corrector lens
- ★ Table tripod for easy polar alignment
- ★ 5X24 finderscope & 1¼" right-angle star diagonal
- ★ 1¼" 25mm (40X) and 9mm (111X) eyepieces
- ★ Fork mount with setting circles, manual slow motion

HIGHLY RECOMMENDED OPTIONS

Model 43 drive corrector uses 12VDC ($130 list)	**$99**
See Meade 2080/LX3 options	
Wedge & field tripod for Meade 2045 ($380 list)	**$298**
Dew shield ($80 list)	**$55**
Solar Filter ($180)	**$139**

SUPER

MEADE
2080/GEM
$885,
w/MCSO
$998

SALE

MEADE
2120/GEM
$1799,
w/MCSO
$1949

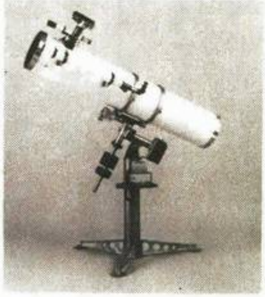
The Meade 2080/GEM and 2120/GEM telescopes include the same diffraction limited optics as the 2080/2120/LX3. Large, stable German Equatorial Mount (GEM) with setting circles, slow motion controls on both axes, large 8X50mm finderscope, 25mm 1¼" eyepiece, integrated polar alignment scope, and heavy duty adjustable height tripod (hardwood for 2080, metal for 2120). The computer control provides automatic object location from an extensive software library of deep-sky objects.

Meade 2080/GEM, 8" f/10 Schmidt-Cassegrain telescope with equatorial mount ($2100 list)	**$885**
Meade 2080/GEM with Multi-coated silvered optics (MCSO) increases transmission 18% ($2300 list)	**$998**
Meade 2120GEM, 10" f/10 Schmidt-Cassegrain telescope with equatorial mount ($4100 list)	**$1799**
Meade 2120/GEM, 10" f/10 with equatorial mount **and with multi-coated silvered optics** ($4300 list)	**$1949**
Dew shield for 2080/GEM	**$72**
Dew shield & accessory tray for 2120/GEM	**$144**
#785 motor and quartz drive corrector system (for photography). **Highly Recommended** ($310 list)	**$219**
#3000 computer control system provides automatic celestial object location ($1500 list)	**add $985**
LUMICON Cassegrain EASY-GUIDER™ with adapter for superb rich-field viewing & photography	**$239**
LUMICON DEEP-SKY Filter™ improves **both** viewing and photography, 1¼" premium	**$79.50**
48mm	**$119.50**

8'' f/6 NEWTONIAN.........$995

$698
(Model 628)

$798
(Model 628C)
6'' f/8 with
motor drive



Model 826, 8'' f/6 Telescope w/accessories

Model 628, 6" f/8 with motor drive ($1220 list)	**$698**
Model 628C, 628 w/2" focuser, 8x50mm finder ($1500)	**$798**
Model 826C, 8" f/6 with motor drive, #680 2" focuser and 8x50mm finderscope ($1640 list)	**$995**

—Collects 78% more light than a 6" telescope.

These Meade Deluxe Series reflecting Telescopes have superb image quality at low or high power. They include an equatorial mount with motor drive, pier, legs, setting circles, 2" rack & pinion focuser, 8X50 finderscope (628C & 826C only), 25mm (48X) and 9mm (135X) 1¼" eyepieces, altitude and azimuth fine adjustments for polar alignment.

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for model 628, 826, DS-10	**$340**
for DS-16	**$440**
Tele Vue 32mm Plossl 1¼" eyepiece	**add $99**
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Illuminated reticle eyepiece & battery pack	**$89.00**

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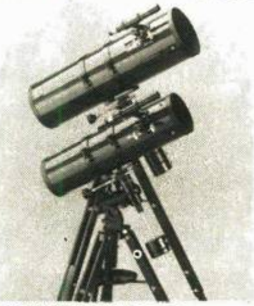

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Model 6600, 6" f/5 Newtonian telescopes ($1400 list)	**$695**

—Best performance & value; bright, wide views.

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—Collects 78% more light than a 6" telescope.

These Meade Professional Series reflecting telescopes yield superb rich-field viewing w/bright images. They include an equatorial mount w/adjustable tripod, setting circles, slow motion controls, 6x30mm view-finder, 1¼" focuser, 25mm & 9mm 1¼" eyepieces & accessory tray.

#784 motor & quartz drive corrector ($310 list)	**$219**
Basic camera adapter (for moon & planets)	**$32**
1¼" LUMICON Easy-Guider (state camera)	**$169**

16'' f/4.5 NEWTONIAN......$1995

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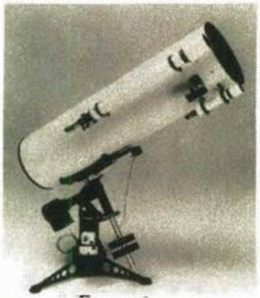


Meade DS-16A with Accessories

The DS Series of 10" and 16" reflecting telescopes are ideal for deep-sky viewing and photography.

DS-10A, 10" f/4.5 with motor drive ($1600 list)	**$995**

—Gathers 56% more light than an 8" telescope

DS-16A, 16" f/4.5 with motor drive ($3140 list)	**$1995**
Sealmaster ball bearings, highly recommended	**add $229**

—Gathers 400% more light than an 8" telescope

Both the DS-10A and DS-16A telescopes include an equatorial mount, #680 2" focuser, motor drive, setting circles and 25mm 1¼" eyepieces. The DS-10A is shipped freight collect.

6x30mm finderscope with brackets ($56 list)	**$42**
8x50mm finderscope with brackets ($130 list)	**$96**

ASTRONOMY
In Focus

Italian Astronomer Really a Priest

Sir / In Michael Carroll's excellent article on Mars, "The Changing Face of Mars" (March 1987), Carroll bestows a fictitious first name on the famous nineteenth-century astronomer Angelo Secchi. Many of Secchi's writings carry the byline P. A. Secchi, but the "P." merely stands for "Padre" because Secchi was a Jesuit priest.

I don't know who originally transformed "Padre" into "Pietro," but all the sources I checked are unanimous in granting Secchi only one first name — Angelo.

Kurtiss J. Gordon
Amherst, MA

Observing from inside the House

Sir / I serendipitously discovered a wonderful way to observe the heavens at low power in supreme comfort: from inside my house through large picture windows with both 7x35 and 11x80 binoculars.

Last year when I built a new house in the country about forty miles west of Minneapolis, I installed new Anderson high-performance windows. They are quite large and the starlight shining through them was visible to the naked eye. Then I got a crazy idea and looked through the windows with binoculars and, much to my surprise, the view was stunning.

In fact, it's difficult to tell you're looking through a window. I have successfully observed objects like M-31, M-33, M-1, M-81, M-82, M-42, and M-43. To determine just how far I could push the limits of the windows, I observed from inside with both 6- and 10-inch Dobsonians at low power, but my success was limited.

I am sure the quality of windows makes a big difference to observing from inside, but everyone should at least try it. Just remember to use as low a power as possible.

The comfort of observing deep-sky objects from a nice, warm living room during January is tough to beat!

Patrick W. Drigans
Buffalo, MN

—Keep in mind that your windows must be made of high-quality plate glass for you to observe through them.

Easier Spider Hunting

Sir / I read with amusement Stephen Ringwood's catalog of futile attempts to reweb his antique filar micrometer in "First, Find Your Spider" (Forum, January 1987).

Spiders that spin webs designed to snare flying insects produce two distinct types of web: support webs, which are long, straight, and nonsticky; and spiral webs, which are thinner and sticky. Since it is quite impossible to tell the spider which type of web to spin when teasing him off the fork arm, dispense with that silly method altogether and adopt the following practical method.

1. Thoroughly clean a window in your garage.
2. Saw off a piece of 4-inch PVC tubing (so you have a ring). Polish the ends but do not deburr them.
3. The next day, when the spiders have spun fresh webs, place the plastic ring behind a single support strand and wipe it onto the open end of the ring, down the outside edge, and off the other end in one smooth movement. Collect half a dozen threads.
4. Place the micrometer wire frame on a tube ring similar to the one you used for the webs, then place both on a piece of white cardboard and illuminate from the front and overhead with a 500-watt quartz halogen floodlight.
5. Place a droplet of "superglue" on each point of a pair of draftsman's dividers. Place the points under a single strand and lift the strand away from the tube ring without touching the other webs.
6. Lay the web across the wire frame's scribe marks and use the method of wiping described in step 3.
7. Apply a droplet of UV curing "Loctite" cement onto the scribe lines and allow ten seconds to dry.
8. Repeat this procedure for the fixed crosshair and position web.

My initial attempt to reweb my bifilar micrometer took eight hours, but a subsequent attempt only took four. The only snag with spider's web is that it readily absorbs moisture from the air and sags after a while if not kept perfectly dry.

C. J. R. Lord, F.R.A.S.
East Sussex, United Kingdom

Quick Dark-Adapting Technique

Sir / Here's a unique technique to quickly adapt your eyes to the dark. In only fifteen seconds you can dark adapt your eyes as much as you normally would in thirty to forty-five minutes.

Look down at your feet — while standing — and blink as hard and as rapidly as you can for fifteen seconds. If there is no stray white-light contamination you will become totally dark adapted. Be careful about dislodging contact lenses when using this technique.

Vic Stryker
Luna Observatory
Luna, NM

— We tried this technique but found it didn't work for us. Try it and let us know if it works for you.

The Case for Cooperation

Sir / I would like to challenge Ray Grasshoff's idea in "The Case against Mars" (Forum, February 1987) that a

U.S.-Soviet Mars mission would be a "dead end" and that we should instead build an advanced space station or a permanent lunar base.

If a permanent base to study lunar geology is valuable, how can Mr. Grasshoff so belittle the knowledge we would gain from Martian samples? What he refers to as "a few rocks and pictures" might transform our view of the solar system's origin and history. The lunar samples certainly did!

If we don't seize this cooperative opportunity, perhaps the Soviets will go ahead without us. No doubt they will share their findings with us. What we will not share, however, is their sense of discovery and thrill of accomplishment.

Marc T. Edwards
Duarte, CA

Giacconi's Heartening Announcement

Sir / Riccardo Giacconi's announcement in "Continuing the Tradition: Amateur Astronomers and the Space Telescope" (Forum, January 1987) that the Space Telescope Science Institute will reserve observing time on the Hubble Space Telescope for amateurs was mighty heartening. Had the offer come from anyone except a scientist, I would have said "nonsense."

Thanks, Dr. Giacconi.

Dave Lewis
Sonoma, CA

Another Copyscope Modification

Sir / The copyscope described in "Building a Copyscope" by Ken Bird (Equipment Atlas, May 1986) was a delight to build, and the resulting telescope is a joy to use.

I do have a modification to offer, however. Though the scope Mr. Bird describes uses 1-1/4" eyepieces, you can convert your telescope to fit 0.965" eyepieces. Simply insert a length of 1-1/4-inch O.D. PVC pipe into the sinkpipe focuser. The resulting I.D. will be just over 1 inch. My 20mm eyepiece fits snugly, though I still have to use a clamp for my 4mm eyepiece.

I experimented a little and found my copyscope can also be used as a telephoto lens. What a versatile scope!

Chris Fernholz
Madison, MN

The Metaphysical Dimensions of Cosmology

Sir / I have just finished reading Tony Rothman and George Ellis' article "Has Cosmology Become Metaphysical?" (February 1987). While I do not completely understand the models discussed, I found the article to be stimulating and thought provoking.

I do find it disturbing that we are unable to "close" the universe and thus cosmic creation becomes cyclic, rather than "flat" or "open" with expansion continuing forever.

That nature has limited the grandest of all creative events to a single occurrence, while all the lesser phenomena, like us, dance a continual ballet of birth, growth, death, and rebirth, is unthinkable to me. Intuition, that most ancient and subtle of metaphysical instruments, tells me we will ultimately find the universe dancing to a cyclic rhythm.

All of this causes me to wonder if scientific inquiry itself is "flat." Could truth also have a receding horizon, one we may approach ever closer without ever reaching? If the finite universe is the artifact of an infinite cause, then perhaps that cause is beyond our knowing.

What does it matter? The true marvel is that we exist at all, let alone are able to cast our wondering eyes toward the sky in search of answers. Perhaps the search itself is more important than finding what we're searching for.

If these questions are not answered in my lifetime, I will not feel cheated but exalted because I was given the gift of wonder. Perhaps this is the ultimate truth: that wonder and delight in the search for answers are the reason for our existence.

John E. Kenney
Redwood City, CA

Where Are You?

ASTRONOMY is trying to find the current addresses of these contributors: Bill Davis, John Gleason, Walter E. Hamler, Leo C. Henzl, Jr., Joseph Kazinca, Joe Lofreddo, Steven Majewski, Boutin Moreau, Jack Newton, E. A. Roberts, Matt Senay, Alan Sifford, Richard Soikkell, and R. Townsend.

Please send us your current address.

Behind the Scenes

Supernova in the LMC

We were just getting the May issue ready to go to press when word came of a naked-eye supernova in the Large Magellanic Cloud. The last naked-eye supernova occurred in the year 1604 and is known as Kepler's supernova. In the 380-odd years since, astronomers have seen many supernovae, but all have been in distant galaxies and all were very faint. The latest supernova, designated SN1987a, provides a tremendous opportunity for astronomers to study a nearby (i.e., bright) supernova.

SN1987a was discovered by University of Toronto astronomer Ian Shelton at the university's Las Campanas station on February 24. Shelton was examining a plate he had taken that night — a 3-hour exposure with a 10-inch astrographic camera — when he found the unexpected 5th-magnitude image. Comparison with plates taken the previous night showed that SN1987a was at least eight magnitudes brighter than it had been the night before. If SN1987a is a typical Type II supernova, as astronomers now think it is, it should have reached a maximum brightness of 1st magnitude in early March and will be fading by the time you read this.

Although the supernova did not occur in our Milky Way Galaxy, it is much nearer and brighter than any other supernova since Kepler's supernova. The Large Magellanic Cloud, one of our Galaxy's satellites, is only 53,000 parsecs distant, and intergalactic space between us and the LMC is free of obscuring dust and gas. If the supernova had occurred in the Milky Way, it might have been dimmed by interstellar dust and gas in the galactic plane.

On the down side, SN1987a lies at −69° declination, too far south to be seen from any of the United States except Hawaii. We hope that our Southern Hemisphere readers will send us some of their photos of this once-in-a-lifetime event.

Observers in both hemispheres can enjoy this summer's rare sequence of mutual eclipses and occultations of Pluto and Charon. These events won't be easy to observe, but I'm sure that many of our readers will rise to the occasion. We're looking forward to hearing from you, whether you observe one or more events with a telescope or capture a complete eclipse sequence on film.

Sincerely,

Richard Berry

Richard Berry
Editor-in-Chief

Photography
in
Astronomy

Photographing Our Nearest Star

by Rick Dilsizian

A white-light solar filter reveals two main sunspot groups crossing the disk. Close inspection of the largest sunspots in this photo shows that each dark umbral core is surrounded by a gray penumbral region. Photo taken by Rick Dilsizian with an 8-inch SCT, a full-aperture filter, Kodachrome 25 film, and a 1/125-second exposure.

Astrophotographers are funny people. They'll spend countless hours in freezing weather to get photos of nebulae, clusters, and galaxies; travel to remote areas of the world to capture a comet; or risk death hiking to the tops of mountains with valuable equipment to get ideal seeing for planetary photographs. But most of them would never abandon any of this for the comparative ease and comfort of photographing nature's most available celestial target — the Sun.

Why is the Sun such a neglected object? After all, it is available every clear day, and you don't have to travel to a "dark sky" to see it! The biggest factor is probably intimidation: astrophotographers are intimidated by the heat and light the Sun puts out. We're all familiar with the childhood experiment of concentrating the Sun's light on a dry leaf with a magnifying glass and watching it burn. Maybe subconsciously we are intimidated by looking at or photographing the Sun, remembering that several seconds of exposure to the Sun's radiation can burn a hole in the shutter — or a retina. The camera is replaceable, a retina is not. The Sun *will* blind the unprotected observer.

Solar Features

To the ancients the Sun was a perfect body with no blemishes on its surface. In 1609 Galileo changed that concept when he observed sunspots sprinkled across the disk with his primitive telescope (although at about the same time other astronomers observed large sunspots with their unaided eyes when the Sun was low in the atmosphere). Thus, the idea of a perfect Sun was forsaken for a Sun that was "imperfect" but more interesting.

With proper filtration the Sun reveals much detail both visually and photographically. Let's look at some of its conspicuous features:

- *The Photosphere*. When we look at or photograph the Sun, we actually see the "surface" of our star — the photosphere. It isn't really a definite surface but the level of the Sun that emits most of the radiation we see. If we look toward the edge of the solar disk, the photosphere appears to get darker. This effect, known as "limb darkening," occurs because light from the limb must pass obliquely through a greater thickness of the solar atmosphere to reach us. Although we can look more deeply into the photosphere at the center of the disk, our line of sight with respect to the limb is through the upper (and therefore cooler) region of the photosphere. Consequently, the limb is obscured. This effect can be seen and photographed.
- *Granulation*. The photosphere is not uniform: it has a mottled appearance called granulation. Granulation is caused by columns of hot gases that rise into the photosphere to different heights, diffuse, and then descend. Individual granules are several thousand kilometers across, or about one to two arcseconds in apparent diameter.
- *Sunspots*. These ephemeral dark regions are actually relatively cool regions of the photosphere. The average temperature of sunspots is approximately 1,500 Kelvins cooler than that of the photosphere, which is about 5,800 Kelvins. The difference in temperature is why sunspots appear darker than the surrounding photosphere: the darkness is mainly a contrast effect. If sunspots could be seen without the surrounding photosphere, they would appear very bright.

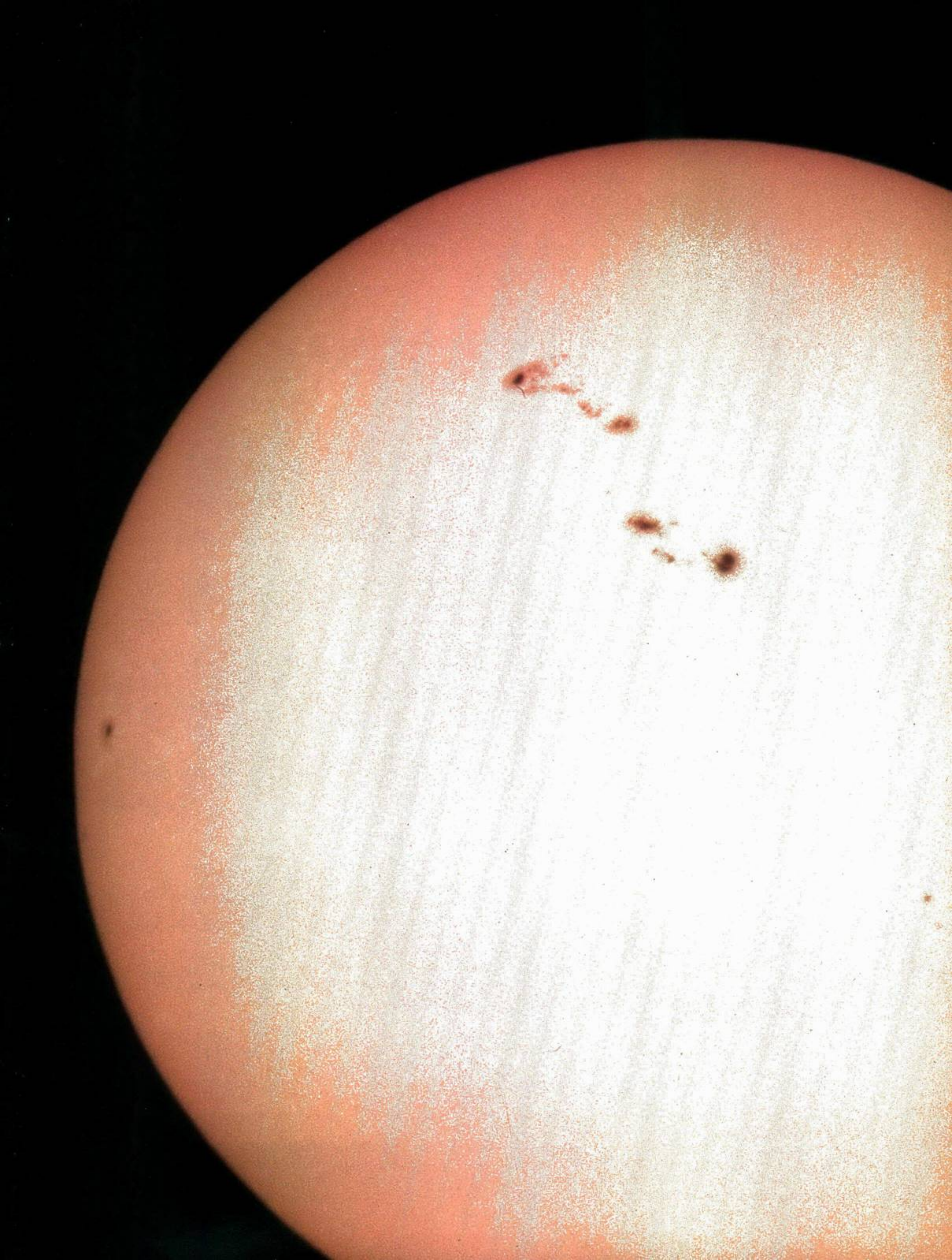
Sunspots can be as small as an individual granule or cover several trillion square kilometers. Their life expectancy is brief — from several hours to several months, though most disappear within a few days' time. Mature spots usually develop two regions: a dark, cool core called an umbra and a surrounding lighter but warmer region called a penumbra.

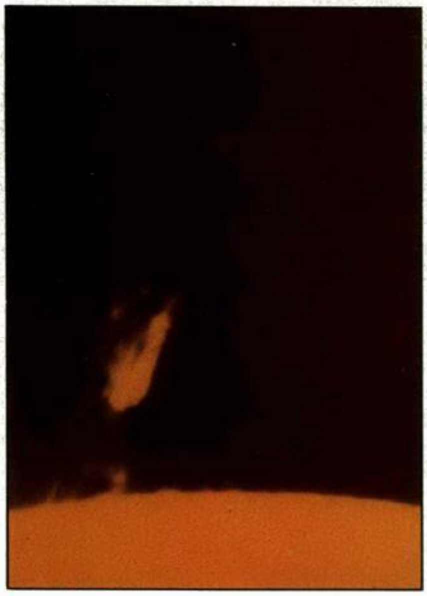
Sunspots appear to be "socially gregarious," tending to congregate in groups of two or more. The total number of sunspots varies during a 22-year, two-peaked cycle that has come to be known, appropriately enough, as the "sunspot cycle." The last sunspot maximum occurred in late 1979 or early 1980; the next should occur in 1990/91.

- *The Chromosphere*. This area of the

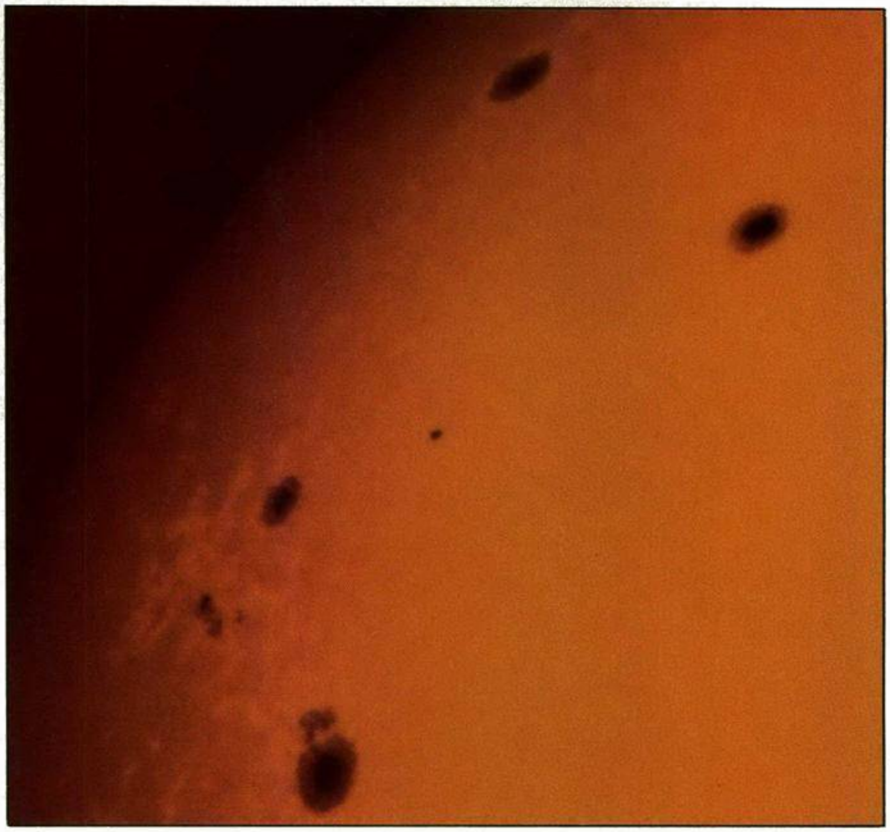
Exposures for Filtered Solar Photography

Film Speed	F/5.6	F/8	F/11
2415 B&W	1/1000	1/500	1/250
25	1/500	1/250	1/125
64	1/1000	1/500	1/250
50	1/1000	1/500	1/250
H-Alpha Exposures for the Photosphere			
2415 B&W	1/125	1/60	1/30
H-Alpha Exposures for Prominences			
2415 B&W	1/8	1/4	1/2



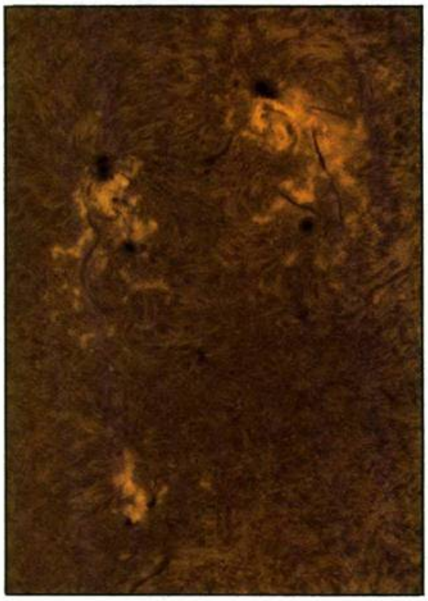


Above: An erupting prominence was captured by Caleb Grodsky in 1980 with an H-alpha filter, a 14-inch SCT, and a 1/4-second exposure at f/33.



Above: The umbral and penumbral regions of sunspots, as well as many bright faculae along the dark solar limb, can be clearly seen in this photo taken by A. W. Steinbrecher with a mylar-coated solar filter, Kodak SO-115 film (now Tech Pan 2415), and 1/500-second exposure.

Right: The face of the Sun, seen in H-alpha light, reveals a granular photosphere marked by sunspots, flares, and dark filaments of gas. Photo by Edwin Hirsch with a 14-inch SCT, an H-alpha filter, Kodak SO-410 (photomicrography) film, and a 1/16-second exposure.



Sun is located immediately above the photosphere and represents a less dense layer of the solar atmosphere. This is the region of "spicules," small jets of glowing gas that appear suddenly and have relatively short lifetimes. The chromosphere is visible only during a total eclipse or when the Sun's disk is artificially blocked.

- *Plages/Faculae*. These features appear above the solar surface when photographed with filters that transmit the light emitted by calcium or hydrogen. Plages appear as bright areas in this filtered light. They are regions in the chromosphere where calcium and hydrogen emit considerably more light than the surrounding area.

Some plages emit light throughout the entire visible spectrum (and not just at wavelengths of calcium and hydrogen); they become visible as white-light phenomena. These special plages are called faculae and are best seen near the darker limb of the Sun.

- *Prominences*. One of the most dramatic sights during a total solar eclipse is tongues of bright, red hydrogen gas being ejected from the surface of the Sun in huge streams extending thousands of kilometers beyond the solar limb. Some prominences (most notably those documented and photographed in 1946 and those observed aboard Skylab in 1973) dwarf the Earth and extend many hundreds of thousands of kilometers from the solar surface into the chromosphere and inner corona.

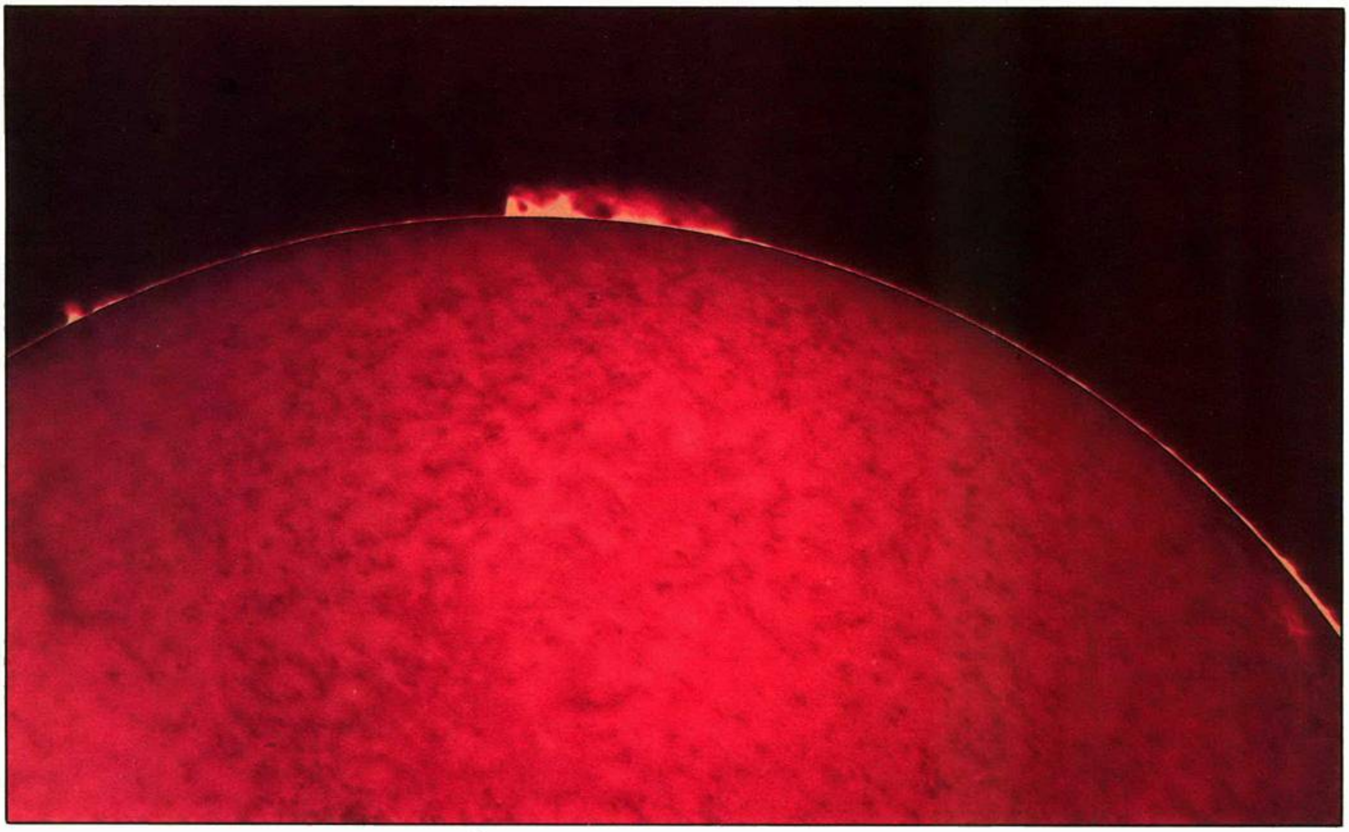
- *Flares*. A flare is an active region that undergoes a sudden, intense increase in brightness. Though most flares shine in the light of calcium or hydrogen, some may intensify across the entire visible spectrum. Flares are usually associated with sunspot groups; they intensify within minutes and disappear within hours of their initial activity.

- *The Corona*. This is the outermost layer of the solar atmosphere. Situated directly above the chromosphere, this is an extremely hot region where all gases exist in a highly ionized state. The corona is manifested as a beautiful atmospheric halo surrounding the Sun during a total solar eclipse. It stretches for millions of kilometers into the interplanetary medium.

White-Light Filter Photography

For all of its dynamics, the Sun is a relatively easy object to photograph. To get the best results, photograph the Sun through as little atmosphere as possible. A good time is in the morning hours and up to 1 p.m. Remember, the less atmosphere you photograph through, the less thermal convection you are likely to encounter and thus the better your seeing. For this reason you should try to photograph the Sun in the summer, when it is highest in the sky. If you live in the higher latitudes, you probably won't photograph the Sun too often in late fall and early winter, especially when it reaches its lowest declination and therefore its lowest elevation at local noon.

You should also try to minimize heat loss from your observing area because heat loss gives rise to air currents that can ruin photographic and visual resolution. Avoid setting up in areas with tar, asphalt, bricks, and pavement; avoid looking over houses and buildings. All of these things get hot, producing rising currents of warm air. Try to observe from a grassy area or over water, because grass and water tend



Solar prominences like these can be photographed using an H-alpha filter. Photo taken by Michael Elkevizth with an 8-inch SCT, SO-115 film, and a mylar filter. This black-and-white print was dyed with brown and red toner.

to stay cool.

Naturally, the Sun is much too bright to photograph without a filter: don't even attempt it. At best you will wind up with a burned shutter. Use a white-light filter, which is a safe, effective means of photographing the Sun. Such filters are available through many telescope dealers.

What does a white-light filter do? It reflects over 99 percent of incident solar radiation, thereby passing a safe amount of sunlight through your system to the camera. These filters are currently made out of aluminum-coated Mylar film or Inconel-coated glass. The Inconel type faithfully reproduces the Sun in both black-and-white and color, while the Mylar filter produces a Sun with a bluish-white color. This is because most of the filter's transmission rises toward the blue end of the spectrum.

White-light filters attach to the front end of the telescope and allow you to take photos at prime focus. Avoid any filter that attaches to the back end of your telescope while leaving the front end unprotected. Heat buildup can shatter such a filter with disastrous results to your telescope, your camera, and you.

There are two types of filters available: off-axis, utilizing only a small portion of the telescope's aperture; and full-aperture, using the full extent of the telescope's aperture. Your choice will depend on local atmospheric conditions. Naturally, the bigger the aperture, the better the resolution. But, because large-aperture instruments cover larger areas of sky than small-aperture instruments, they show a greater number of turbulent air cells and thus tend to render a shimmering image when the atmosphere is unsettled. Using only part of the available aperture — as an off-axis filter does — cuts down on the amount of visible turbulence but sacrifices full-aperture resolution. However, if you are blessed with a stable atmosphere most of the time, the full-aperture filter is the better choice in terms of total resolution.

Use the following checklist to set up your telescope for photography in white light:

1. Cover the front end of your telescope *securely* with the filter. If the filter comes off during photography, you could be instantaneously and permanently blinded.

2. Cover the finder scope's front end. Since the finder scope will also be aimed toward the Sun, its focused light could inadvertently burn you or, should you unconsciously look through it, damage your eye.

3. Attach your camera to your telescope with a prime-focus attachment. Use an air-bulb type cable release for vibration-free shutter control.

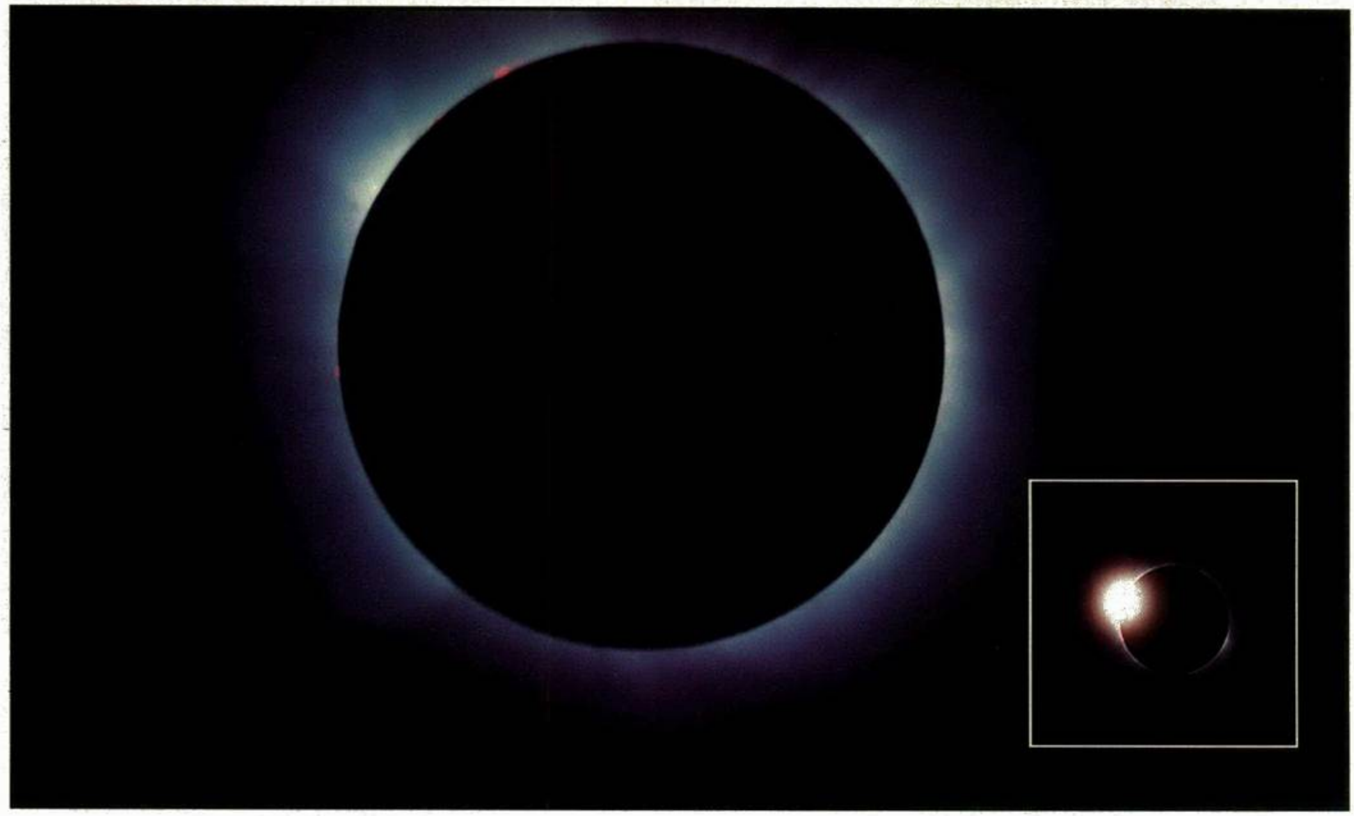
4. Aim the telescope in the approximate direction of the Sun. As you point the telescope, watch its shadow on the ground. When the shadow is smallest (i.e., when the tube length is parallel with the incoming rays of the Sun), the Sun should be in or near the field of view. Because your filter blocks 99 percent of all sunlight, the field of view in the camera will appear black until the Sun comes into the frame. Once you've found the Sun, focus the camera and you will be ready for solar photography.

Which film should you use? I suggest Kodak Tech Pan 2415 for black-and-white photography. This film's inherently high contrast, fine grain, and extremely crisp resolution are ideal for resolving the penumbral and umbral regions of sunspots and for photographing the limb-darkening effect as well as faculae near the limb.

For color work use a slow, high-definition film such as Kodachrome 25, Kodachrome 64, or Fujichrome 50. All three offer superb definition and higher contrast than their medium-speed counterparts. Fast films are not necessary because the shutter speed is fast enough with slow films. Table 1 gives starting exposure times for Inconel-coated glass and aluminum-coated Mylar filters. Experimentation will refine these times. Remember, use these values only as a starting point. Conditions vary according to the elevation of the Sun and the amount of haze in the atmosphere: the lower the Sun is in the sky, the longer the exposure. If the table calls for an exposure of 1/250 of a second, bracket by taking three frames: one at 1/500, one at 1/250, and one at 1/125 of a second. Local viewing conditions will dictate which of the three will be the best on a given day.

Hydrogen-Alpha Photography

Within the last ten years it has become possible to photograph the Sun through



A total solar eclipse is one of the best times to photograph the Sun's outer atmosphere. In this 1/4-second exposure taken at Tuban, Java, during the 1983 eclipse, red prominences and the radiant corona recorded equally well. A longer exposure would have overwhelmed the prominences with coronal light. Photo by Mike Harkey.

Inset: Pam Dilsizian captured the "Diamond Ring" effect from Indonesia during the 1983 eclipse using a 500mm, f/8 telephoto lens.

a filter that passes the red light of hydrogen, known as "H-alpha" radiation. The Sun is composed mostly of hydrogen: excited hydrogen atoms leave their "fingerprints" in the visible part of the solar spectrum as the Balmer series of spectral lines. Photographing the Sun in this spectral region easily captures plages, flares, and spicules, as well as prominences.

H-alpha filters (also referred to as Hα) are expensive: they can cost as much as a good telescope! However, they do allow extensive photography of much detail within the photosphere and chromosphere. H-alpha filter systems have two major components: a filter that attaches on the front end of the telescope system and the H-alpha narrow-band filter (the narrower the band, the higher the contrast) that attaches at the prime focus before the camera is attached.

Because the *filter* passes only red light, thus rendering a red image of the Sun, color photography is of no real value here. Instead, the best resolution and contrast

Partial Solar Eclipse Exposures

The following shutter speeds apply to filtered white-light solar photography and are recommended on a trial basis. Variations in filter densities may require different exposures.

Film Speed	F/5.6	F/8	F/11
		Up to 75%	
25	1/500	1/250	1/125
2415 B&W	1/1000	1/500	1/250
50	1/1000	1/500	1/250
100		1/1000	1/500
200			1/1000
		90% Immersion	
25	1/250	1/125	1/60
2415 B&W	1/500	1/250	1/125
50	1/500	1/250	1/125
100	1/1000	1/500	1/250
200		1/1000	1/500
400			1/1000
		95% Immersion	
25	1/125	1/60	1/30
2415 B&W	1/250	1/125	1/60
50	1/250	1/125	1/60
100	1/500	1/250	1/125
200		1/500	1/250
400	1/500	1/250	1/500

can be obtained with Tech Pan film. The exposure guides in the table on page 38 can be used as starting points for work with H-alpha filters. The major problem with H-alpha work involves atmospheric turbulence. Because shutter speeds are longer than they are in white-light work by a factor of four, air turbulence in the atmosphere is that much more detrimental to the image. Once again the key to changeable conditions is bracketing exposures.

Solar Eclipse Photography

You have the opportunity to take the most dramatic type of solar photographs during partial and total eclipses. Because you probably won't know what kind of sky conditions you will be facing, it's best to calculate exposure times before the day of the eclipse.

How long you make your exposures during the partial phase depends more on your film speed than on the amount of Sun covered. Throughout most of the partial phase you will likely use a single exposure setting because the Sun's brightness doesn't diminish that much. But, as the Sun enters the crescent phase, limb-darkening effects require a change to a longer exposure. However, even though less light is arriving at the camera, you must *still* use a solar filter. Again, do not look directly at the Sun during this phase.

The recommended exposure times during the partial solar eclipse phase are given in the table on page 42.

If you use a telephoto lens, use one with a focal length of 200mm or longer. The best telephotos have focal lengths between 500mm and 1200mm. Wide-angle and 50mm lenses, as well as short focal-length telephotos, are virtually useless because they don't provide a large enough image scale: the Sun appears as a white dot (or a black dot during totality).

During totality you can photograph several subjects: prominences, appearing as dramatic red spikes along the limb of the Sun; the inner corona (that area immediately above the chromosphere); and the outer corona. Because of their brilliance prominences should be photographed with relatively short exposures. The inner corona requires longer exposures, and the outer corona even longer exposures because of its intrinsic faintness.

The key thing during *totality* is removing the solar filter from the front end of the telescope. You need not fear being blinded during totality because the photosphere is blocked by the Moon. The table on page 43 should serve as a guide for exposures during totality.

A Solar Eclipse Checklist

Let's go over a preliminary checklist for photographing the Sun during a total solar eclipse.

1. Make sure the camera/telescope system is functional before setup. During the Indonesian expedition I did not check out the mechanical system on my camera and the automatic shutter mechanism failed during totality!

2. Secure the camera/telescope system to a sturdy, heavily dampened tripod to avoid vibration from the camera shutter mechanism or the wind. Mentally project the Sun's path across the sky to be sure you have an unobstructed field of view for the total phase of the eclipse.

3. Make sure you have at least two rolls of film, one for the partial phase of the eclipse leading to totality and the second for totality itself. You certainly don't want to run out of film during totality. Load the second roll approximately five minutes before total immersion by the Moon.

4. Wear an eyepatch to allow one of your eyes to become dark-sensitive during the partial phase. At totality you will then have one "good" eye with which to observe and to use for photography.

5. Is your camera focused? Is the film loaded? Is the solar filter attached to the lens or telescope? If so, begin partial-phase photography.

6. Always allow the tripod to "settle down" for several seconds after each exposure so the vibration does not ruin the next photo in the series.

7. Five minutes from totality rewind the first roll of film and load your second roll. Don't be cheap about film!

8. Just before totality remove the solar filter and photograph Bailey's Beads — irregular splotches of sunlight passing through the rugged lunar terrain just prior to totality — and the dramatic "diamond ring effect" — the final, brilliant flash caused by the last bit of sunlight appearing through a lunar valley.

9. As totality begins, remove the eyepatch. Check the focus and then start a series of exposures. Vary your exposure times throughout the entire shutter speed range of your camera so you can get quality images of prominences, the inner corona, and the outer corona. The key point to remember during this phase is not to be greedy — wait for the camera/tripod system to settle down before shooting the next frame.

10. As you near the end of totality, photograph the diamond ring effect and Bailey's Beads again and get ready to put the solar filter on. Once you've made it through this part of the eclipse you may be emotionally drained, but try to photograph the subsequent partial phase anyway. Afterward, pack up and celebrate!

The Sun reveals a wealth of detail to the astrophotographer who selects the proper filter, the right film, the correct exposure time, and who is, above all, cautious. Any astrophotographer can take stunning photographs of our nearest star. And those photos are just a sunny day away.

Shutter Speeds during Totality

Film Speed	F/5.6	F/8	F/11
		Outer Corona	
25	1/2	1	2
2415 B&W	1/4	1/2	1
50	1/4	1/2	1
100	1/8	1/4	1/2
200	1/15	1/8	1/4
400	1/30	1/15	1/8
		Inner Corona	
25	1/30	1/15	1/8
2415 B&W	1/60	1/30	1/15
50	1/60	1/30	1/15
100	1/125	1/60	1/30
200	1/250	1/125	1/60
400	1/500	1/250	1/125
		Prominences	
25	1/250	1/125	1/60
2415 B&W	1/500	1/250	1/125
50	1/500	1/250	1/125
100	1/1000	1/500	1/250
200		1/1000	1/500
400			1/1000

Rick Dilsizian teaches at Westchester Community College in Valhalla, New York, and is an avid astrophotographer. His photos appear regularly in ASTRONOMY, and his latest article, "Gaining Confidence with Piggyback Astrophotography," appeared in the April 1987 issue.

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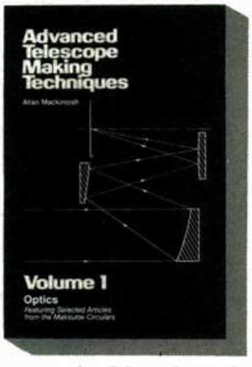
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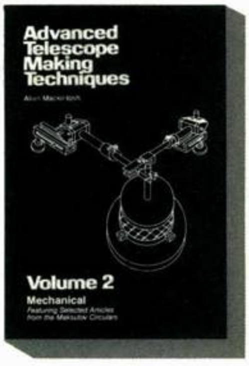
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Equipment Atlas

Building Fun Telescopes for Less than $10

by Robert Monaghan

Telescopes started out as a playground accident: the spectacle-maker's children played with some discarded lenses and by chance hit upon a combination of lenses that made distant objects look close. Within a few years word of the discovery spread to Italy, where an ambitious scientist, one Galileo Galilei, turned an "optic tube" skyward and started a major revolution in astronomy.

Too few of us play with lenses anymore. We prefer to buy ready-made telescopes and computerized cameras and then carefully follow the directions for their use instead of experimenting with bits and pieces of optical equipment and learning from our experiments.

Here are some simple ideas for things you can make and do with lenses, things you can really enjoy trying. There's something here for any curious person — a beginner, an old pro, or someone somewhere in between. The optics may be surplus, obsolete, or gathering dust in your closet or camera bag. Obsolete junk has one big advantage: it's really cheap. Break out the junk and start experimenting! And don't be surprised if some of these crazy ideas become a permanent part of your stock of astronomical equipment.

Start off by dredging up that old 8mm movie camera, the old kind with a screw-in lens. Remember that relic from the days before home video? If you find an old camera with a three-lens turret, you're in luck, but the really obsolete, non-Super-8, know-nothing camera is perfect. These usually bring a couple of dollars at yard sales.

Why search for these ancient 8mm cameras? The answer is simple: the lens, used backwards, makes a very acceptable eyepiece. A normal lens for such cameras is roughly 13mm focal length at f/2. The aperture is around 7mm in diameter when fully open. The lenses are high-quality, highly color-corrected formulas designed to put images on 8mm film that will be blown up to wall size. It's relatively easy to make good-quality glass lenses in such small sizes. Even so, the original lens often costs a substantial sum, especially converted into today's dollars. Because they're obsolete, they're a real bargain.

Do you have an old 2.4-inch refractor? You know, the same kind you saw being sold as a "Comet Clobberer" during the Halley craze but is twenty years old? Try this: compare the 8mm movie camera lens to your economy 0.965" eyepiece. The first time I did this I was amazed. The movie camera lens gave greater sharpness and clarity than the eyepiece did, and it hadn't cost me a cent. Most of the old color fringing was gone too. So, for a couple of bucks at most, you'll have an amazingly good quality eyepiece. Your old "Comet Clobberer," equipped with its obsolete 8mm camera lens, now turns out to be a nice scope. You might even feel the urge to start using it again. Sure, I know a standard eyepiece might be even better, but try finding one for the cost of a burger.

To make your junk-box eyepiece more permanent, use some metal or plastic tubing, epoxy, black paint, a black cardboard stop (optional), and *voila!* — you've just built your own experimental eyepiece. It may even become your favorite.

Now let's try building a telescope. What can you use for an objective lens? We need a good magnification ratio, and a fair amount of "glass" area would add to its appeal. Low cost is essential too. Where can you find such a beast? Enter the photographer's screw-in diopter lens set. These were used for close-up photography before macro-zoom lenses were invented. Millions of diopter lens sets are lying around gathering dust — inconvenient and "obsolete." (There's that magic word again!) Practically any such lens will do for experiments — we aren't particular. Any filter size is fine too. So what if the lens was made for an Exacta camera? The larger the glass area the better. One or two dollars per lens seems to be the going price in stores and ads, which really isn't bad for a 50mm diameter lens with a focal length of 1000mm. The camera store will call it a +1 diopter lens.

At the hardware store pick up a 1-meter length of 2-inch-diameter PVC pipe for the tube, a pipe coupler to serve as a lens retaining ring and dew cap, and a 2"-to-1" coupler to hold your 8mm-movie-camera-lens eyepiece. The magnification will be 1000mm/13mm, or about 80x. Assemble it and you have built yourself a fun telescope. It's about twice as powerful as the one Galileo used and probably better optically. For $10 you can afford to let this scope take a beating (translation: it's a perfect project scope for kids). Or would you rather have them play with yours?

Want low magnification? You can get it by using a longer focus eyepiece or a shorter focus objective. Will the 50mm lens from that decrepit SLR your brother-in-law dropped in the lake (and you fished out) fill the bill? The camera doesn't work anymore, so try the lens. What can you lose? If it works, you'll get 1000m/50mm, or 20x.

If you buy a three-lens close-up kit, you can build quite a variety of scopes. Get the clerk in your favorite camera store to dig around in that box of stuff the store couldn't sell the last time it held an 80 percent off sale. Aha, here they are — three close-up lenses for $8.95. Offer him $5. Note that the focal length of diopter-

Photos by Art Schmidt

rated close-up lenses is 1000mm divided by the strength of the lens in diopters, so a lens rated +2 diopters has a focal length of 1000mm/2, or 500mm. With one eyepiece coupler unit and three lens-and-tube sections you can make three scopes for about $15, or $5 each.

These scopes will have magnifications from 15x to 80x, a nice complement to the magnification you can get with your primary scope but beyond that of ordinary binoculars. You should be able to see craters on the Moon, the phases of Venus, the ovalness of Saturn (if not its ring system), Jupiter's disk and satellites, hundreds of double stars, and dozens of deep-sky objects.

Optically, though, diopter lenses leave quite a bit to be desired, especially in terms of color correction. More obsolete junk to the rescue. Unearth that 135mm f/2.8 telephoto lens you don't use anymore. It's a high-quality, well color-corrected optical assembly. Set it to infinity and attach it to your 8mm movie camera eyepiece lens. How? Mount the eyepiece on the rear lens cap, preferably the older metal style.

Drill out a central hole and epoxy in an appropriate bit of PVC pipe or metal

26x
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tubing. Blacken the inside with flat black spray paint. Plug in your "eyepiece" and set the focus: you've got a nice 10x40mm finder with excellent optics.

For really low magnification dig out that 50mm normal lens, attach your eyepiece to it, and you've got a dandy 4x finder. This is an especially satisfying way to recycle obsolete screw thread camera lenses in today's bayonet-mount world. Radio antenna clamps and muffler clamps are a big help in mounting such finders on a telescope, though you may well think of something better. Be creative.

A 200mm f/4 camera lens gives you a nice 16x scope with a respectable 50mm aperture. Since virtually any lens from any camera will work, feel free to experiment. Haunt flea markets. Visit a few pawn shops. Poke around a surplus store. Scrounge from your photographer friends. Take your junk to a swap meet and see if you can trade it for somebody else's junk. Discovery is a thrill.

Once you've built a couple of telescopes and spotting scopes, you may want to investigate making a few more eyepieces. Lenses for 16mm movie cameras were frequently traded in for zoom lenses. Many are gathering dust in camera stores with prices around $10. Typically these are f/2 or faster 25mm lenses. They are high quality, highly color corrected, and quite a bargain. Any design we've mentioned for an 8mm movie lens ought to work with a 16mm camera lens — and the price is just a few dollars more. Again, have fun experimenting with all of them!

If you don't have a nice loupe for examining those tiny, millimeter-size astro images on your slides, you can make one. Cut the sides out of a [illegible]″-to-1″ PVC pipe adaptor to form a little tripod and slide your movie lens eyepiece in. A lens mounted in a coupler can be used directly on a light table.

Experiment with whatever optics you can find around the house, in the attic and closets, and in neighborhood garage sales. Sure, you'll find stuff you'll never use. But you might also turn up a real winner for just a few bucks!

If you're an old pro, here's your reward for browsing through this article. These 8mm and 16mm lenses are superb copy lenses for making one-step duplicates of astronomical slides. Construction is simple: remove your present lens from its bellows or extension tubes. Mount the 8mm movie lens on a camera body cap over the bellows with the inner surface of the lens facing out.

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Using this rig is easy. Place a slide on a light table and use standard bellows focusing techniques. You can blow up an astrophoto 500 to 2,000 percent with crisp definition, good contrast, and excellent color fidelity. Try it. You probably already have the lens. Even if you don't, all you have to lose is a couple of dollars. I predict you'll be pleased with your bargain bellows enlarging lens, especially after you price an equivalent bellows lens. What you save in cold cash will please you even more.

If you're a serious astrophotographer, consider using an 8mm or 16mm movie lens for eyepiece-projection photography. Those lenses were designed to project super-sharp images on tiny film, and they work beautifully in reverse for enlarging tiny planetary images. You can use them in a commercial eyepiece-projection rig or put together something of your own.

The telescopes you build with obsolete optics may not be world-class creations. They may be a bit wiggly around the edges or show somewhat more chromatic aberration than you'd like. But you've gained something you couldn't get in a store-bought scope: the fun of doing. Try whatever lenses you can find and experiment with different combinations. So what if the images are a bit fuzzy? You'll learn how telescopes work, and why.

Use these cheap but good-quality scopes as gifts for the kids or as ideas for the budding astronomer. One final thought: when you've done your thing with them, don't put them back in the junk box. Pass your creations on to some of the neighborhood kids. Give them a chance to learn and play too. It's only fair. After all, aren't kids the ones who invented telescopes in the first place?

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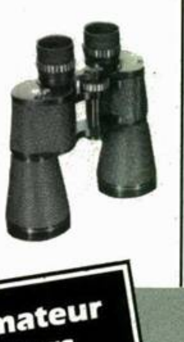

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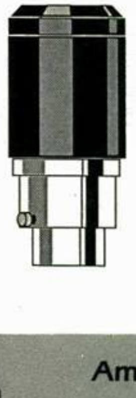

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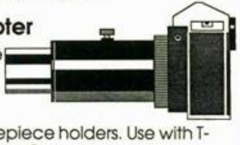

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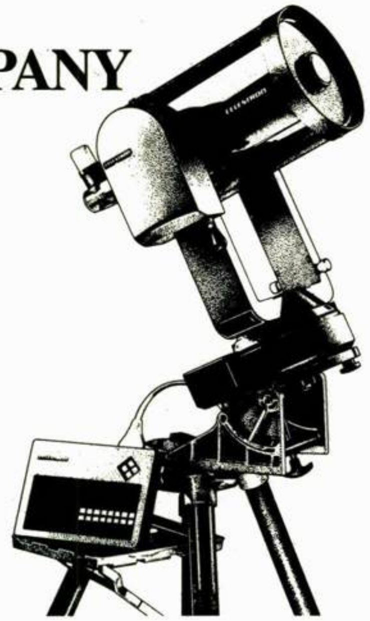

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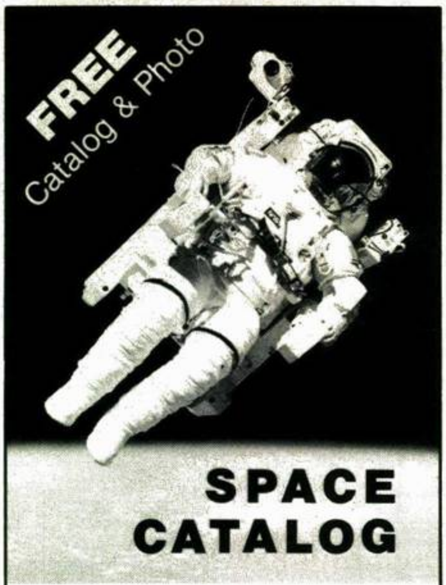
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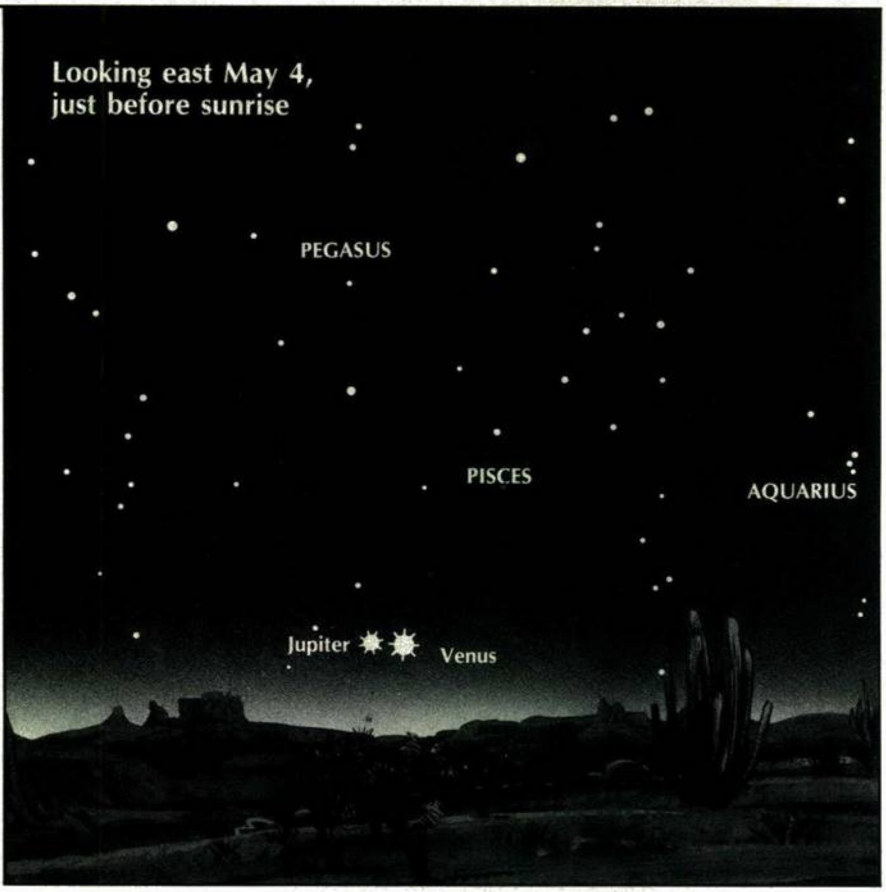
Eye on the Sky

Conjunction of Jupiter and Venus

by Robert Burnham



The Wanderers

For half of May the evening sky contains only one planet visible to the naked eye. **Mars** shines orange-red west of Gemini in Taurus. Since this region sets soon after the Sun, spotting Mars may be a challenge if your viewing site is hemmed in with trees or buildings. Find an open space or rooftop that gives you a wide view to the west and northwest.

Mars has a magnitude of 1.7, which is about the same as that of the star Castor in Gemini. On the 1st, the crescent Moon passes about 4° (eight Moon-diameters) north of Mars. Photos taken at the same time on the evenings of April 30 and May 1 will clearly show the Moon moving "backward" (eastward) against the stars. Use a tripod, a medium telephoto lens set wide open, fast film, and exposures that run 1/2, 1, 2, and 5 seconds. (Also see the diagram on page 56).

Around May 15, **Mercury** appears below Mars after sunset and will be visible there until the third week of June. (Mercury and Mars will pass near each other next month.) Mercury is brightest when it first appears (magnitude −1.3 on the 15th) but fades steadily, reaching magnitude 0.1 on May 31. Its color may appear creamy-white to reddish-white, though not as red as that of Mars. Because Mercury's elevation remains less than 11° during the entire apparition, your viewing site needs a flat west and northwestern horizon. Also, don't hesitate to use binoculars the first few times you look — they'll make seeing the elusive planet much easier.

By about 11 p.m. both Mercury and Mars will have slipped below the horizon. The next planet to look for is **Saturn**, which will be rising into view in the southeast around the time Mars disappears in the northwest. Saturn's stellar backdrop is the constellation Ophiuchus, but you'll probably find the planet more easily by referring to the star Antares in the Scorpion (see the Night Sky map). Antares is orange (like Mars), while Saturn is distinctly whiter and brighter and lies to Antares' left.

For information on viewing the Moon, planets, and deep-sky objects with telescopes, see **The Backyard Astronomer**.

The last two naked-eye planets are **Jupiter** and **Venus**. They make a splendid eye-catching pair this month low in the east just before sunrise. On the morning of May 4 (see the diagram above) they will lie less than a degree apart. Since Jupiter is at magnitude −2.1 and Venus at −3.9, the sight will be spectacular. The planets are relatively close from about the 1st to the 10th, so if clouds cover the sky on the 4th, don't give up hope. This will be one of the year's best photo opportunities, ideal for a series extending over several mornings.

The **Eta Aquarid meteor shower** reaches peak activity in the predawn hours of May 5, and the shower is still strong a day before and after. The meteors appear to come from near the star Eta (η) Aquarii (hence the name) in the "Water Jar." They derive from Halley's famous comet and, although this object has now faded from view, keep an eye on its two associated meteor streams and look for changes in the number of meteors per hour. (The Orionids of October 21 are the other Halley meteors.)

Opposite page: The Moon and Venus in the evening sky in early 1985. Photo by David L. Rights.

At a dark site you would normally see ten to fifteen meteors per hour, but this year who knows? In any case, the Eta Aquarids are fast, bright, colored yellow, and leave long trails. After moonset (around 2 a.m. daylight time) the sky will be fully dark. For meteor photography use a tripod, a normal or medium wide-angle lens set wide open, fast film, and exposures that run 10 minutes to half an hour. (The brighter your sky, the shorter the exposure.) Aim the lens about 45° away from the radiant in the constellation to catch the longer meteor trails.

The Starry Sky

On May evenings the **Milky Way** circles the horizon and the Galaxy's north pole (marked *NGP* on the Night Sky map) lies high overhead. Because bright stars line the Milky Way, tonight's sky is relatively dim. Even worse, during the middle two weeks of May — from First Quarter until Last — moonlight washes out all but the brightest stars. Therefore, to learn the constellations properly, you should plan a mid-evening drive out of the city during the first or last week of the month. Take your copy of ASTRONOMY and a flashlight with its lens covered by red paper

May Night Sky

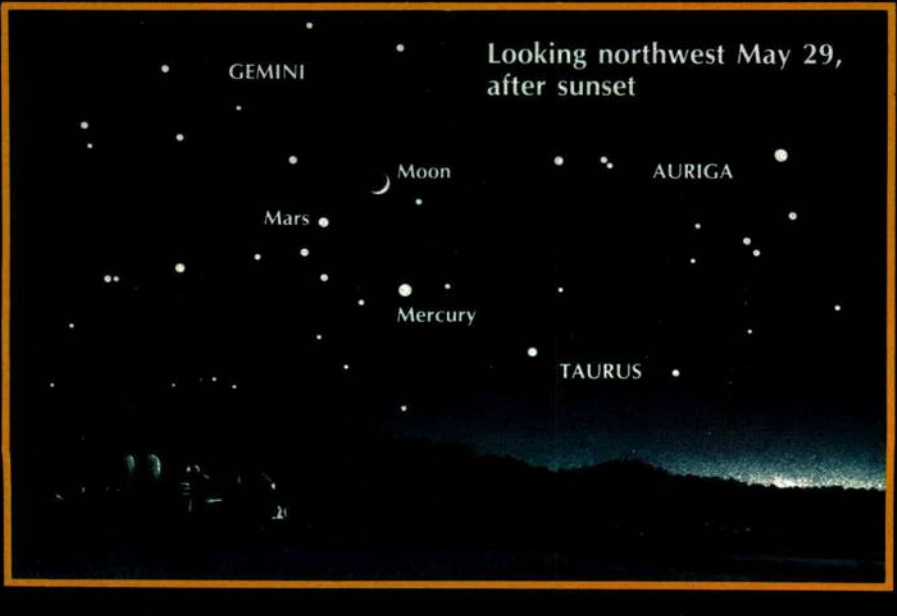
First Quarter
May 6
10:26 p.m. EDT

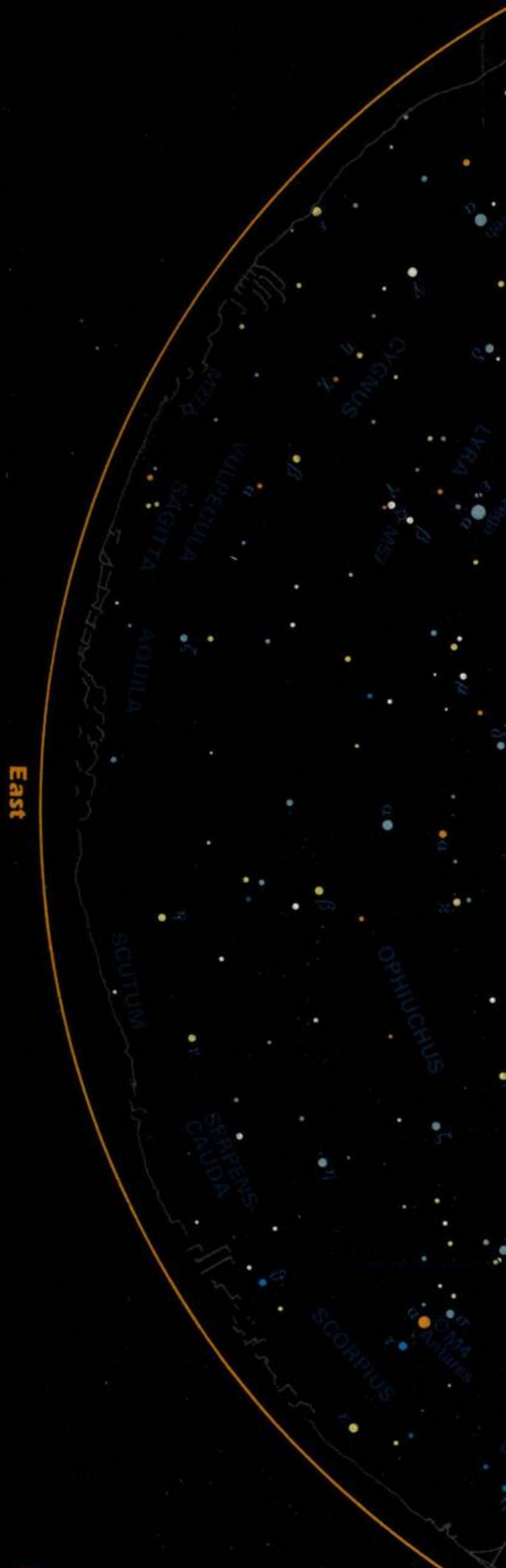
Full Moon
May 13
8:50 a.m. EDT

Last Quarter
May 20
12:02 a.m. EDT

New Moon
May 27
11:13 a.m. EDT

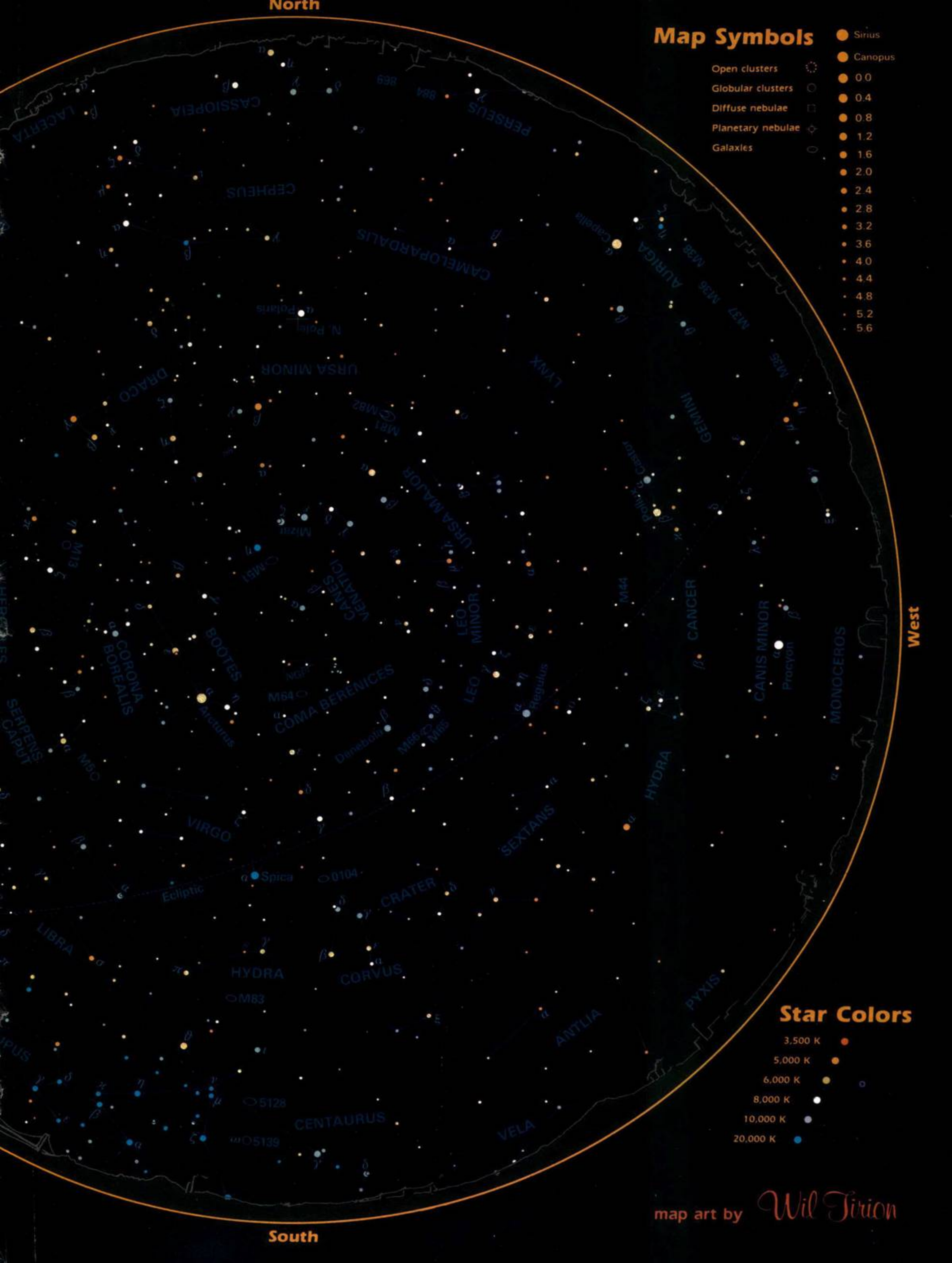
3rd	The Moon reaches its greatest distance from Earth (for the first of two times this month) at 9:43 p.m. EDT: 251,469 miles (404,689 kilometers).
4th	Venus and Jupiter lie close together in the predawn sky.
5th	Today is the peak of activity for the Eta Aquarid meteor shower.
6th	First Quarter Moon occurs at 10:26 p.m. EDT.
7th	Mercury passes superior conjunction with the Sun and moves into the evening sky. Start looking for it low in the west-northwest in about five days.
11th	The star Spica is occulted by the Moon for viewers in Alaska (around 3 a.m. daylight time) and Hawaii (4 a.m. daylight time).
13th	The Moon is Full at 8:50 a.m. EDT.
14th	The Moon occults Antares in Scorpius, but the event is not visible from the Western Hemisphere.
15th	The Moon is closest to Earth at 6:34 p.m. EDT: 225,946 miles (363,614 kilometers).
20th	Last Quarter Moon is at 12:02 a.m. EDT.
27th	New Moon occurs at 11:13 a.m. EDT.
31st	The Moon again reaches its greatest distance from Earth at 2:50 p.m. EDT: 252,045 miles (405,616 kilometers).


Looking northwest May 29, after sunset



The Star Dome shows how the sky looks at:

11:30 p.m. daylight time on May 1
10:30 p.m. daylight time on May 15
9:30 p.m. daylight time on May 30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Canopus
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0.4
0.8
1.2
1.6
2.0
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2.8
3.2
3.6
4.0
4.4
4.8
5.2
5.6
LACERTA
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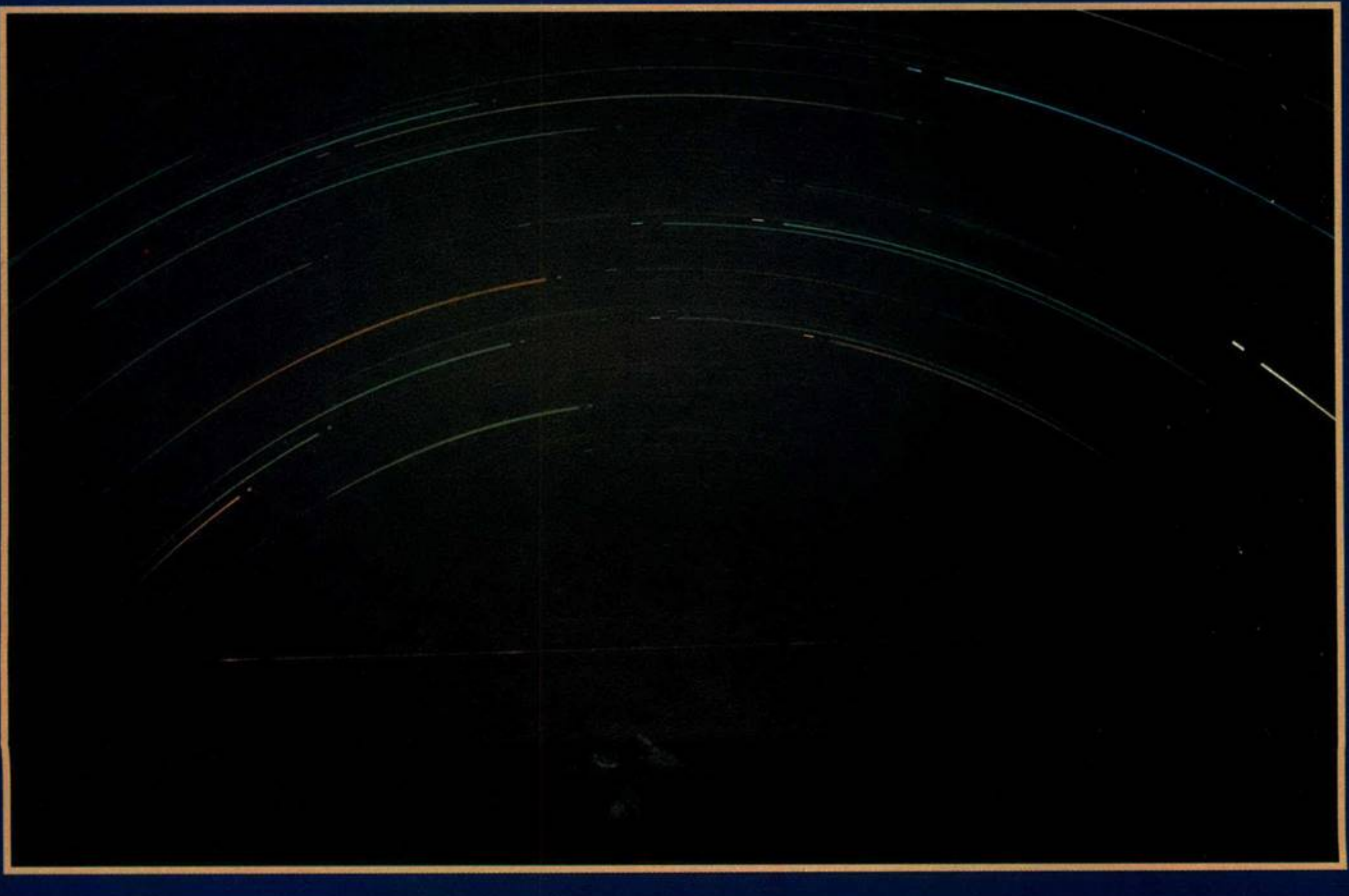
South

map art by Wil Tirion



Right: The constellation Corona Borealis is a distinctive wreathlike grouping of stars high overhead during May. Photo by Gregory Walz-Chojnacki.

Opposite page, top: The December 18, 1986, conjunction of Jupiter and Mars was uniquely captured by John Cisetti, who used a 28mm lens at f/2.8, Kodak 400 film, and a 21-second exposure.

Opposite page, bottom: In this parade of southern circumpolar stars, Canopus is the bright star setting on the right side of the photo. The "False Cross," made up of stars from the constellations Vela and Carina, trails from the center of the frame to the right, and rising to take its place is the true Southern Cross. Alpha and Beta Centauri are rising from the left side of the photo. The length of the exposure was 4-1/2 hours. Photo by Dewey Vanderhoff.

and go at least ten miles beyond where the streetlights end.

If you have a clear view to the west, you will see white Procyon in **Canis Minor** the Lesser Dog gleaming over the fields. To its upper right two 1st-magnitude stars, Pollux and Castor, stand like sentinels at the head of their elongated constellation, **Gemini** the Twins. (Orange Mars may be visible as it sets below.) To the lower right of Castor lies yellow Capella in Auriga the Charioteer.

Well above Procyon the "Little King," Regulus marks the forepaws of **Leo** the Lion, now crouched as if to spring over **Cancer** the Crab. Leo's front end looks like a reversed "?", while his hindquarters form a right triangle: Denebola is corrupted Arabic for "the tail of the Lion." **Coma Berenices**, Berenice's Hair, is a quietly beautiful speckle of stars above Denebola.

High in the south a 1st-magnitude white star named Spica is the main luminary of **Virgo** the Maiden. (The star is more prominent than the map leads you to think.) Virgo was often seen as the goddess of grain and plenty, and Spica supposedly represents an ear of wheat in her hand. The central region of the nearest large cluster of galaxies lies where Virgo and Coma join. The cluster contains 2,500 members, the brightest dozen of which can be seen in small telescopes.

Below Virgo and Leo the long, sinuous form of the Water Snake **Hydra** carries a Crow (**Corvus**) and a Cup (**Crater**) on its back. (Trace Hydra by locating its head between Procyon and Regulus.) In legend Corvus was sent to fetch some water in a cup for Apollo, but the Crow dawdled by a fig tree, waiting for the fruit to ripen so he could eat it. He returned carrying Hydra and claimed the snake had delayed him. Exasperated, Apollo threw the lying bird into the sky along with the empty cup and the snake.

Below Hydra, **Centaurus** rears up from his southern homeland. Little of the Centaur is visible from latitude 40° or higher, but viewers in the southern United States should point their binoculars at two objects. NGC-5128 is Centaurus A, an enigmatic radio galaxy that looks like a dim spot of haze in 7x50s. The other object, Omega (ω) Centauri, is a giant globular cluster that lies just to the south.

When you face southeast, the orange star you see hovering over the trees is 1st-magnitude Antares, the eye (some say the heart) of **Scorpius**. Between Antares and Spica swing the Scales of **Libra**, a large, faint, diamond-shaped constellation formed mainly of 2nd- and 3rd-magnitude stars (see Skylore). High above Antares and almost overhead shines warm Arcturus, the zero-magnitude main star in **Bootes** the Herdsman. Bootes forms a tall "ice cream cone" with two steadying "feet" at its southern end. It has also been called Icarius — *not* Icarus, the famous youth whose waxwork wings failed him — in honor of the poor fellow who taught mankind how to make wine and was cudgeled to death by the first people to awake with hangovers.

Next to Bootes is a small semicircle — **Corona Borealis** the Northern Crown. Its α-star is magnitude 2.2 Alphecca, which is Arabic for "the bright one of the dish." High in the north on the other side of Bootes hangs the ever familiar Big Dipper, the seven brightest stars of **Ursa Major** the Large Bear. The two end stars on its bowl point downward to Polaris, the north star and luminary of the Lesser Bear, **Ursa Minor**.

Two star-figures are rising in the northeast. **Hercules** was a famous strongman, whose exploits were detailed in last month's Skylore. His constellation is a keystone of four 3rd-magnitude stars with "arms" and "legs" running outward from the corners. (The pretty globular cluster M-13 is barely visible to the naked eye as a soft smudge in binoculars. Look between Eta [η] and Zeta [ζ] Herculis.) **Lyra** the Lyre is small but easy to locate since it packs several 3rd- and 4th-magnitude stars into a small but distinctive pattern next to zero-magnitude white Vega. Lyra represents the instrument invented by Hermes and given to his brother Apollo, who in turn passed it on to his son Orpheus.

Skylore

The constellation figure we call Libra is something of an anomaly. First, it is the only one of the zodiacal twelve that does not represent a living creature. And second, it is of relatively recent origin, being only about two thousand years old.

When you look along the ecliptic, little catches the eye in the expanse between ruddy Antares and white Spica. Libra is not very prominent; in fact, under anything but a really dark sky you'll have trouble finding it. Originally Libra's stars belonged to Scorpius, the next constellation to the east. Libra then represented the out-thrust claws, the *khelai*, of the Scorpion, and the entire figure was considered a double constellation. (Tracking the Sun's course for twelve months by means of eleven star-groups apparently didn't bother the ancient myth-framers.)

But this configuration wasn't entirely fixed. In some ancient legends Virgo — as Astraea, goddess of justice — held a sword in one hand and scales in the other. A minor Greek tradition also saw scales in these stars. R. H. Allen's *Star Names* mentions that the sacred books of India as well as an Indian zodiacal chart showed these stars in the shape of a balance.

Our Libra, however, dates from 46 B.C. when the astronomer Sosigenes of Alexandria was chosen by Julius Caesar to reform the calendar. (To the Romans, Egypt was the home of all occult knowledge.) Sosigenes' work became known as the Julian calendar and held sway until our present Gregorian calendar replaced it during the late sixteenth century. (In most of Europe, that is. England and America didn't switch until 1752, and Russia not until its revolution in 1917.)

Sosigenes also thought it prudent to honor Caesar another way as well. He chopped off the Scorpion's claws and created a fresh zodiacal constellation from their stars. The new figure, of course, was none other than Caesar himself, holding a scale and dispensing justice and wisdom. (The legends are silent about whether he wore a blindfold or not, but we can be sure he was wearing the traditional toga.) Supporting the newly created legend was the fact that two thousand years ago the Sun entered this region at the time of the autumnal equinox, when the lengths of day and night are perfectly *balanced*.

Although he was cheated of fame when the calendar he created was named, Sosigenes still received a small measure of revenge from history. No sooner did the real Caesar become dust than he began to disappear from the constellation, leaving only the scales in his place.

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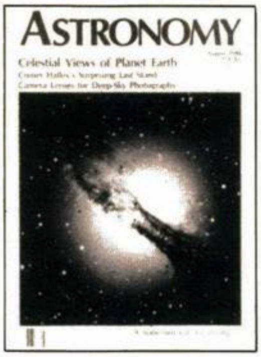

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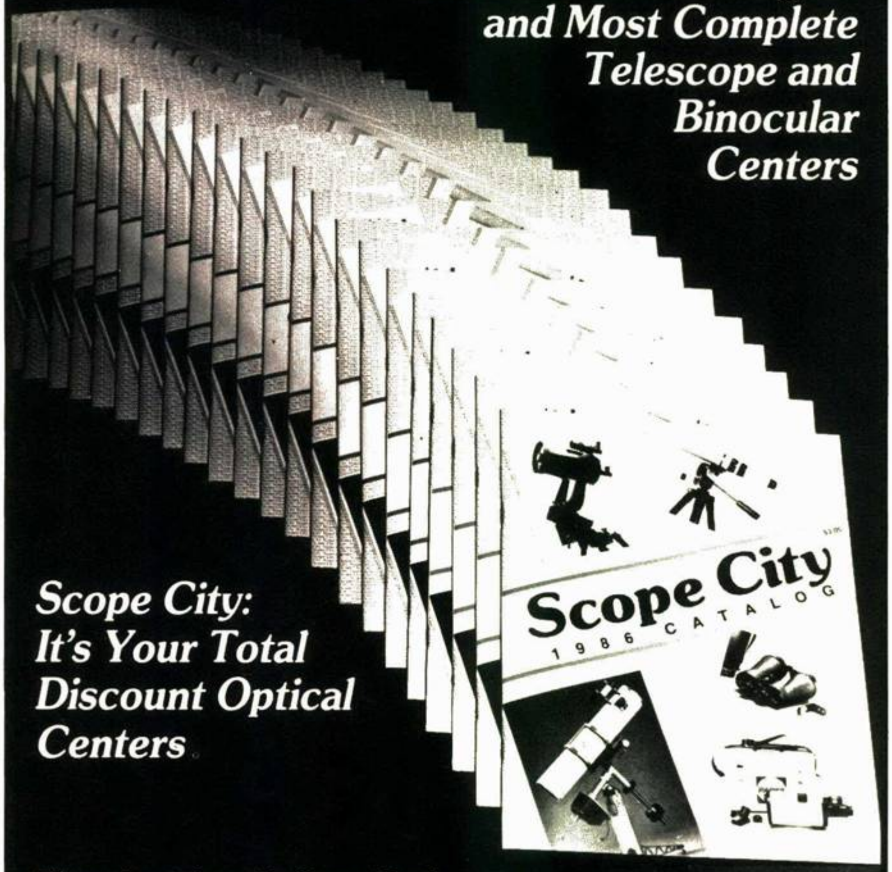

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Gazer's Gazette

Observing Spring Galaxies with Binoculars

by Craig Crossen

Few observers of the night sky would contend that binoculars are the ideal instrument for observing galaxies. So, many people are surprised to learn that several dozen galaxies are visible in a pair of 10x50 binoculars. Although the view won't rival that in a 16-inch reflector, many galaxies appear bright enough in binoculars to be interesting. And if you use zoom binoculars, which let you increase the magnification to 12x or 15x, the contrast between the sky background and the galaxy's subtle glow is increased. Binoculars are also more portable and easier to use than small telescopes. And it's amazing to consider that you're viewing a gigantic object millions of parsecs away with an instrument held in the palm of your hand.

The Requirements

Galaxy searching with binoculars is not easy. To do it successfully you need, first and foremost, a moonless night at a site well away from city lights. Second, you'll need a trained eye, which may take some time to acquire. But once you know exactly what you're looking for, finding galaxies becomes relatively easy.

Begin your "training" with some naked-eye observations. Take a look around the sky and work on spotting the faintest stars and clusters you can see. Without a good idea of what you're hunting for, galaxies will elude you. To prepare your eye for spotting smaller, fainter galaxies, pull out your binoculars and take a look at some of the brightest globular clusters. The appearance of globulars is similar to those of galaxies, but clusters are typically brighter and are therefore easier to practice on.

Finally, you'll need a good pair of binoculars. Giant binoculars like 11x80s or 20x80s make galaxy hunting fairly easy, but they are expensive and require a tripod, which puts them in the small telescope class for all practical purposes. We're concerned instead with everyday, garden-variety binoculars.

Probably the best size to start with is 10x50 binoculars, which provide 10x magnification and an objective diameter of 50 millimeters. Many galaxies can be glimpsed with 7x50 binoculars, though a 7x magnification neither darkens the sky background nor magnifies a galaxy's image very much. Consequently, many galaxies that appear as distinct disks or patches in 10x50s will appear like fuzzy stars in 7x50s (and perhaps disappear altogether in 7x35s, which gather only half as much light as 50mm binoculars).

Keep in mind several observing techniques while searching a field for a faint galaxy or studying the image of a galaxy you have found. First, maintain your dark adaptation. Second, remember to use averted vision: your retinas are more sensitive to faint light toward their edges. Third, do *not* keep the binoculars rock-solid steady at all times. (This is difficult anyway, even when you are braced against a post or reclining in a lawn chair.) If you allow the field to move in slow, casual sweeps, the contrast difference between galaxy and sky will be easier to detect.

Galaxies form and exist in groups and clusters ranging anywhere from a handful to many dozens of members. The Milky Way and the Andromeda Galaxy are the two brightest of a modest little group of thirty-one galaxies, most of which are dwarf galaxies, called the Local Group. Galaxy groups in turn cluster in huge aggregations called superclusters. Some of the finest views of galaxies through binoculars are the brightest members in a galaxy group. The fall sky holds several bright examples, such as the Andromeda Galaxy, M-33 in Triangulum, and a group of bright galaxies in Sculptor, but since it's spring, we'll look in detail at the spring sky's offerings.

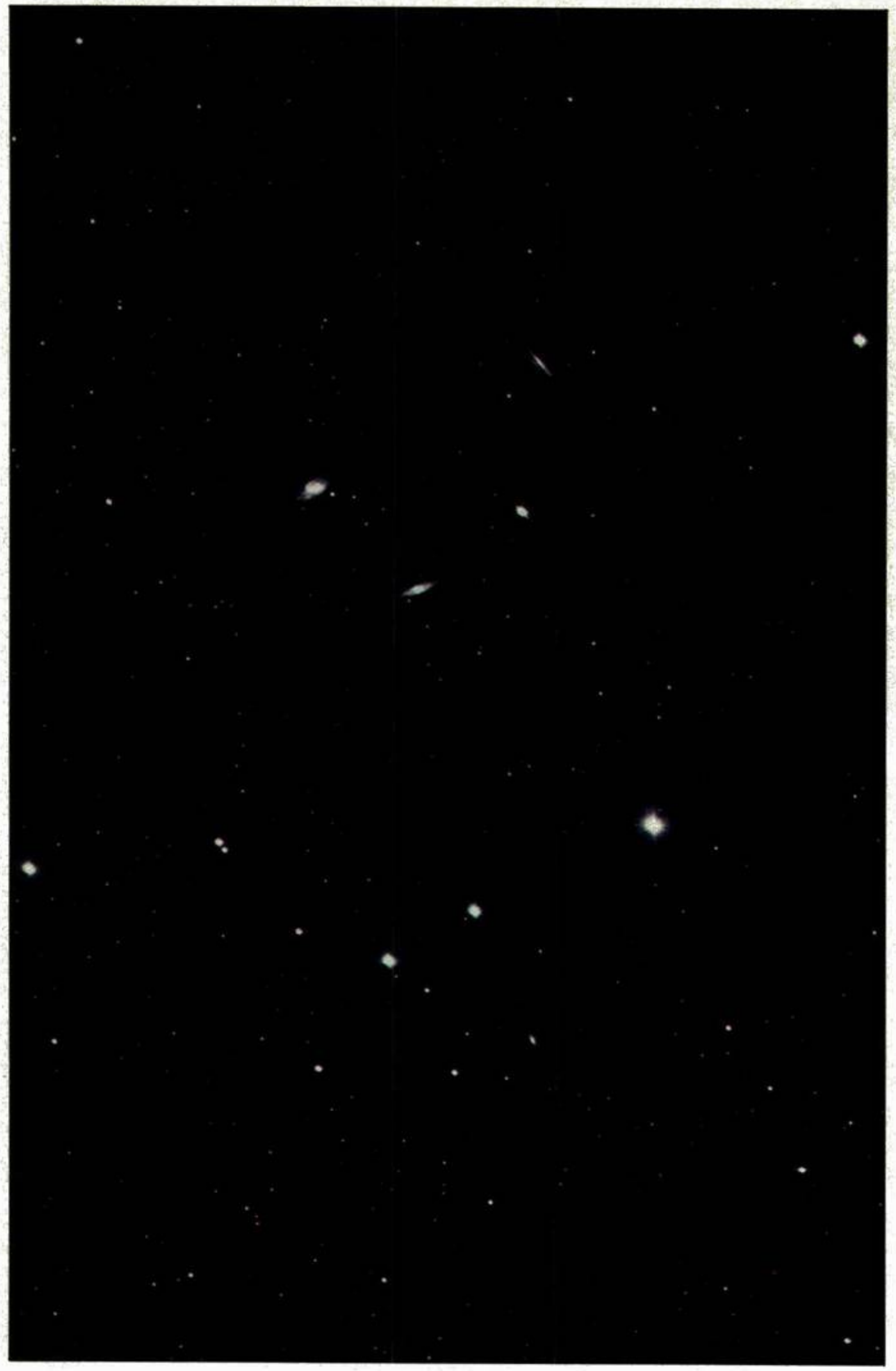
The Ursa Major Group

One of the best galaxy pairs for binoculars is formed by M-81 and M-82 in northern Ursa Major. Both of these galaxies are bright with total magnitudes of 6.9 (M-81) and 8.4 (M-82), and they lie only 38′ apart. M-81 appears as a small oval nebulosity surrounded by a diffuse halo of much fainter light aligned north-south. M-82 is a thin spindle of silvery light in an east-west elongation and measures 11.2′ by 4.6′, which is small in comparison to M-81's impressive dimensions of 25.7′ by 14.1′. (All dimensions in this article include extremely faint light invisible in binoculars, so the galaxies will appear significantly smaller in binoculars.)

A pair of 7x50 binoculars shows the different orientations of the two galaxies, but higher magnification is necessary to see the more subtle differences between them. Both galaxies are abnormal: M-81 is a large Sb-type spiral with an unusually bright, large, and star-dense central hub visible as an oval smear of nebulosity with a bright, almost starlike condensation in its center; M-82 is an active galaxy ejecting material from its nucleus, though this activity is invisible in binoculars.

M-81 and M-82 form the heart of the Ursa Major Galaxy Group. At a distance of 5 megaparsecs this group lies in our cosmic backyard. Galaxies belonging to this group lie scattered over a large area extending from Kappa (κ) Draconis on the east, through northern Ursa Major, and west into Camelopardalis. An excellent galaxy for binoculars is the bright Sc spiral NGC-2403, an Ursa Major group member some 14° west-southwest of the M-81/M-82 pair in the star-poor wastes of western Camelopardalis. NGC-2403 shines at magnitude 8.4 and is quite large, measuring 17.8′ by 11.0′, but it is difficult to find because it's isolated. In 10x binoculars you will see this galaxy as a small, bright, elongated core surrounded by a compact elliptical halo. After you find the object, study it carefully, moving the binoculars' field of view around slowly and taking in

M-51, also known as the Whirlpool Galaxy, is one of the finest galaxies for binoculars. In 10x50s M-51 appears as a double patch of nebulosity with a bright core characterizing the larger half. Photo by Pierre Schwaar, who used a 20-inch f/5 Newtonian, hypered Konika SR 1600 film, and a 30-minute exposure.



Above: A bright face-on spiral, M-83 in Hydra, appears in binoculars like a large, nebulous disk of hazy light. Photo by Jim Barclay, who used a 12.5-inch f/6 reflector, Ektachrome 400 film, and a 60-minute exposure.

Left: The Leo Group of galaxies contains the bright spirals M-65, M-66, and NGC-3628 (center), and NGC-3593 (top). All of these objects are visible in binoculars; M-65, M-66, and NGC-3628 appear together in the same field of view. Photo by Mace Hooley, who used an 8-inch f/1.5 Schmidt camera, hypersensitized Tech Pan film, and a 10-minute exposure.

Right: Centaurus' NGC-5128 is one of the largest and brightest galaxies in the sky; in 10x50s it appears as a bright oval haze bisected by a thin, gray band of dust. Photo by Jack B. Marling, who used a 24-inch f/7.5 Cassegrain, hypersensitized Fujichrome RD 100, and a 50-minute exposure.

all you can. You will soon notice that your ability to see faint detail is growing with each observation.

The M-101 Galaxy Group

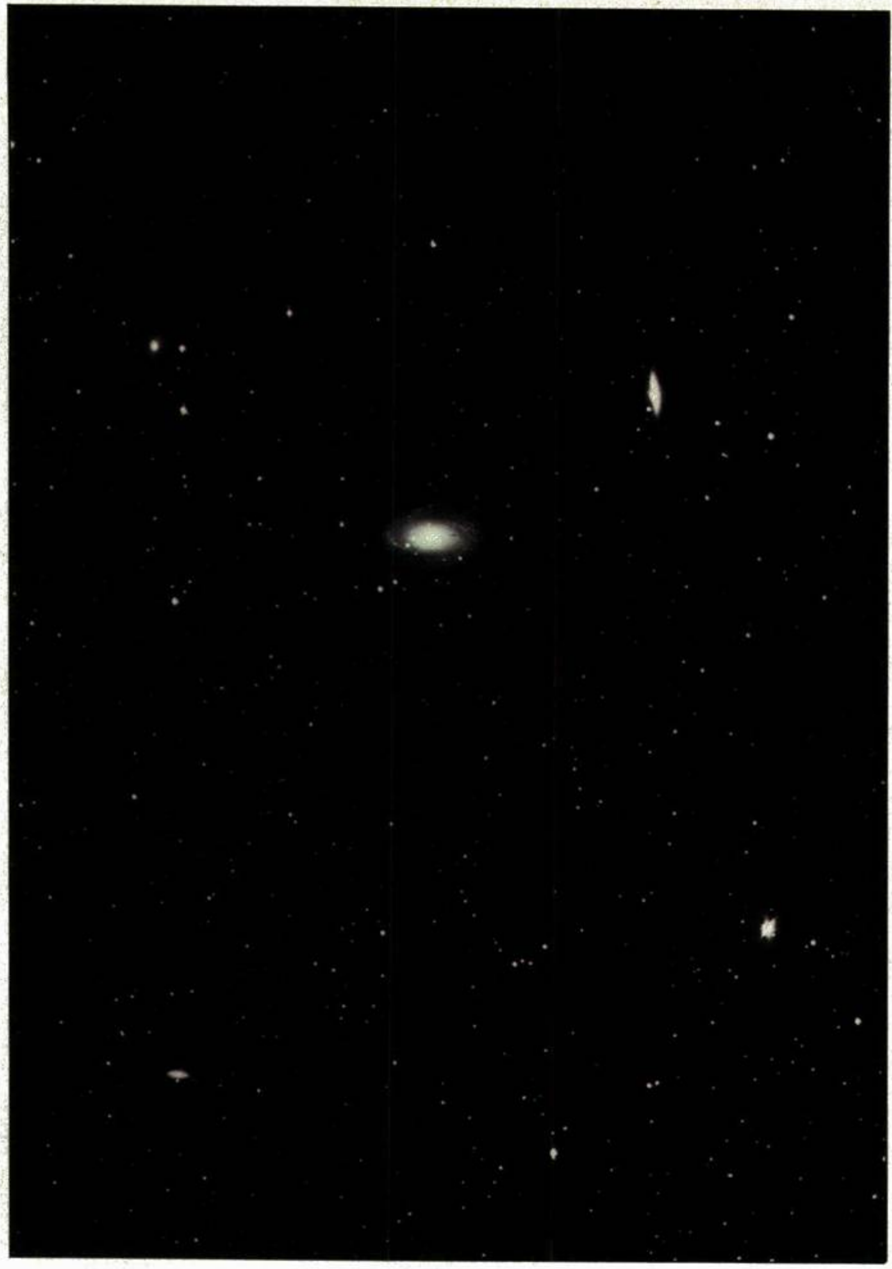
One of the largest galaxies in the sky is the beautiful face-on spiral M-101. Spanning 26.9′ by 26.3′, M-101's relatively bright total magnitude of 7.7 is so spread out that the galaxy's surface brightness is extremely low. Unless you're observing under a very dark sky, you may not see M-101, at least not without careful searching, in a pair of 7x50 binoculars. As you search for it keep in mind that you're looking for an object one-fourth the size of the Moon but with an average brightness not much greater than the sky itself.

M-101 is about 5 megaparsecs distant, and its diameter is probably well over 30 kiloparsecs. It is a bright member of a large galaxy group scattered loosely around the handle of the Big Dipper. Another member of the group is M-63, an Sb-type spiral about 1.5° north of the group of four 5th- and 6th-magnitude stars — 18, 19, 20, and 23 Canum Venaticorum. M-63 shines at magnitude 8.6, measures 12.3′ by 7.6′ across, and in binoculars appears as a thin streak positioned west-southwest to east-northeast. If you study this galaxy carefully, you will see an 8th-magnitude foreground star lying near its western edge.

The finest member of the M-101 Galaxy Group is the great Whirlpool Galaxy, M-51, located about 3.5° southwest of Eta (η) Ursae Majoris. In 7x binoculars M-51 appears as a small circular disk. Although it is less than half the size of M-101, it is much easier to spot because its surface brightness is much higher. In 10x50 binoculars M-51 is a fascinating sight because it is pear-shaped: the larger and brighter southern section is an Sc-type galaxy — the Whirlpool itself — and the smaller lobe on the northern side is a smaller companion galaxy called NGC-5195.

Other Nearby Galaxy Groups

Another nearby galaxy group is the Canes Venatici I Cloud, a smattering of bright galaxies about 7 megaparsecs away. The CVn I Cloud includes such notable objects as M-94, M-106, and possibly M-64 in central Coma Berenices. M-94 is a nearly face-on Sb-type spiral that shines at magnitude 8.2 and spans 11.0′ by 9.1′. This galaxy appears like a fuzzy star in 10x50 binoculars because most of its light comes from its rather small central hub



The brightest pair of galaxies, Ursa Major's M-81 and M-82, are easily visible in any binoculars. Fainter but still visible are NGC-3077 (upper left) and NGC-2976 (lower left). Photo by Mace Hooley, who used an 8-inch f/1.5 Schmidt camera, hypersensitized Tech Pan film, and a 10-minute exposure.

and inner spiral arms. On a dark, transparent night you might be able to detect a large, misty halo surrounding M-94's condensed core.

M-64, another Sb galaxy, is a better object for binoculars because it has a more interesting shape. M-64's magnitude is 8.5, and its dimensions are 9.3′ by 5.4′, which make it visible as an elongated disk. This galaxy is easy to find since it lies just 1° east-northeast of the 5th-magnitude star 35 Comae Berenices.

But M-64 isn't the best galaxy for binoculars in the CVn I Cloud. That honor belongs to M-*106*, a magnitude 8.3 Sb-type system measuring an enormous 18.2′ by 7.9′. Even 7x50 binoculars show M-106 as a sharply defined spindle elongated southeast-northwest and immersed in a uniformly bright halo of nebulosity. M-106 lies in a rather star-poor field about 4° east of Chi (χ) Ursae Majoris, so locating the big galaxy is something of a challenge

Another close group of galaxies lies in Centaurus and holds a 30°-long chain of half a dozen bright galaxies. The chain's northernmost point is about 10° south of Spica; from there the galaxies extend down through the tail of Hydra and into central Centaurus, ending only about 10° north-northeast of the Southern Cross. The brightest galaxies in this group are NGC-5068 in extreme southern Virgo; M-83 in Hydra; and NGC-5253, NGC-5102, NGC-5128, and NGC-4945, all residents of Centaurus. The members of this galaxy chain have an average distance of 4 megaparsecs, which gives the chain itself a length of 2.1 megaparsecs.

Three of the galaxies are unusual. M-83, which on photographs looks like a typical Sc galaxy, has had four supernovae in the past sixty years — as many as have been observed in our Galaxy in the entire past millenium. NGC-5253 has a peculiar structure: a smooth elliptical shell of nebulosity surrounding a bright rectangular inner region. The galaxy has had two brilliant supernovae in the past century. (Both of NGC-5253's supernovae reached magnitude 7.2, implying an absolute magnitude of −20.5, an output of light equal to that of our Galaxy.)

The Centaurus Galaxy Group is not well situated for most Northern Hemisphere observers. M-83, the northernmost object in the group, is situated at −30° declination, so it culminates at least 20° above the horizon in the forty-eight contiguous United States. It is a fine object for any pair of binoculars since it has a blue-light magnitude of 8.2 and measures 11.2′ by 10.2′ across. A typical 7x50 view of this galaxy shows a large, roundish spot of nebulosity with a bright, almost starlike center.

Even better than M-83 is the unusual galaxy NGC-5128, culminating only 20° above the horizon for observers in Florida and Texas. This galaxy appears as a large (18.2′ by 14.2′), bright (magnitude 7.0) oval of nebulosity bisected by a thin dark band of dust. The view of this galaxy in any pair of binoculars is tremendous!

The Leo Galaxy Group

A galaxy pair rivaling M-81 and M-82 is made up of M-65 and M-66, which are separated by only 21′ and found about 2.5° south-southeast of Theta (θ) Leonis. M-66 is an Sb galaxy measuring 8.7′ by 4.4′ with a magnitude of 9.0. M-65 spans some 10.0′ by 3.3′, shines at magnitude 9.3, and is a type Sb galaxy. In 7x50 binoculars M-66 is clearly visible as a tiny patch elongated in a northwest-southeast direction; M-65 requires the additional magnification of 10x50 binoculars to show its north-south orientation.

Under excellent observing conditions you may spot, using 10x50s, a small streak of nebulosity 35′ north of M-66. This is the edge-on spiral galaxy NGC-3628. The galaxy is almost as bright as M-65 (magnitude 9.5), but its large size (14.8′ by 3.6′) makes its surface brightness low, and therefore the galaxy is difficult to spot. Fortunately NGC-3628's location is well marked: about 20′ north-northeast of M-65 is a 7th-magnitude star, and NGC-3628 lies another 20′ northeast of this star.

The trio composed of M-65, M-66, and NGC-3628 forms the heart of a cluster of about a dozen galaxies spread between Theta (θ) and Iota (ι) Leonis and centered approximately 8 megaparsecs away. This cluster is, however, just the eastern half of the Leo I Galaxy Cloud. The western part of the Leo I Cloud inhabits the region midway between Regulus and Theta and Iota Leonis and has at least twenty

Spring Galaxies for Binoculars

Object	M#	R.A. (2000)	Dec.	Mag.	Size	H
NGC-2403		7h 36.9m	+65°36′	8.4	17.8′ x 11.0′	Sc
NGC-3031	M-81	9h 55.6m	+69°04′	6.9	25.7′ x 14.1′	Sb
NGC-3034	M-82	9h 55.8m	+69°41′	8.4	11.2′ x 4.2′	Pec
NGC-3623	M-65	11h 18.9m	+13°05′	9.3	10.0′ x 3.3′	Sb
NGC-3627	M-66	11h 20.2m	+12°59′	9.0	8.7′ x 4.4′	Sb$^+$
NGC-4258	M-106	12h 19.0m	+47°18′	8.3	18.2′ x 7.9′	Sb$^+$ pec
NGC-4374	M-84	12h 25.1m	+12°53′	9.3	5.0′ x 4.4′	E1
NGC-4406	M-86	12h 26.2m	+12°57′	9.2	7.4′ x 5.5′	E3
NGC-4486	M-87	12h 30.8m	+12°24′	8.6	7.2′ x 6.8′	E1
NGC-4826	M-64	12h 56.7m	+21°41′	8.5	9.3′ x 5.4′	Sb$^-$
NGC-5055	M-63	13h 15.8m	+42°02′	8.6	12.3′ x 7.6′	Sb$^+$
NGC-5128		13h 25.5m	−43°01′	7.0	18.2′ x 14.5′	S0 pec
NGC-5194	M-51	13h 29.9m	+47°12′	8.4	11.0′ x 7.8′	Sc
NGC-5236	M-83	13h 37.0m	−29°52′	8.2	11.2′ x 10.2′	Sc
NGC-5457	M-101	14h 03.2m	+54°21′	7.7	26.9′ x 26.3′	Sc

members, including M-95, M-96, and M-105. This cluster is better observed with giant binoculars or a rich-field scope than with small binoculars, but in 10x50s M-96 is visible as a tiny fuzzy spot.

The Core of the Supergalaxy

By now it should be obvious there are many nearby galaxy groups in the spring sky. If we look toward one special place in the spring sky, the so-called Realm of the Galaxies, the densest clusters of galaxies in our part of the universe and the core of our supergalaxy are visible. The inner region of our supergalaxy lies specifically toward southern Coma Berenices and western Virgo.

Examine the distribution of galaxies in a detailed star atlas like *Sky Atlas 2000.0*, and you will notice that a great number of galaxies lie throughout the Big Dipper, Canes Venatici, Coma Berenices, and western Virgo. The density of galaxies falls off quickly as you move away from this axis; some galaxies lie in eastern Leo, Leo Minor, and around the stars 109 and 110 Virginis, but relatively few galaxies lie in the other spring constellations.

Notice that the Ursa Major and Centaurus galaxy groups lie on the same line as the galaxy stream from the Big Dipper through western Virgo. This indicates that our supergalaxy is a large, flattened structure. And since flattening implies rotation, the Local Group and other galaxy groups in the local supergalaxy must be revolving about the supergalactic core in periods that must be many hundreds of millions of years. The diameter of our supergalaxy is probably over 30 megaparsecs.

Before venturing into the core of our supergalaxy, take one last look back out of the supergalaxy. *Sky Atlas 2000.0* will show you that the autumn constellations are generally galaxy poor. Capricornus, for example, occupies a fairly large area of the sky but has only one galaxy brighter than 13th magnitude. Cetus offers two tight galaxy clusters, the M-77 group and the NGC-1052 group, and Eridanus provides a fairly rich galaxy group around its bright star Tau (τ). In addition, Fornax contains the rich galaxy cluster surrounding NGC-1365.

This line of galaxy groups continues into the far southern sky and includes a group in northeastern Horologium and two loose clusters in Dorado. The galaxy groups from Cetus down through Dorado seem to contain outlying members from a neighboring supergalaxy that we are viewing edge-on, since they reside at 15 to 20 megaparsecs' distance.

The heart of our supergalaxy is the great Coma-Virgo Galaxy Cluster, centered midway between Beta (β) Leonis and Epsilon (ε) Virginis. This cloud of galaxies measures about 10° across and contains the great spirals M-58, M-88, M-90, M-99, and M-100 and the giant ellipticals M-49, M-59, M-60, M-61, M-84, M-85, M-86, M-87, and M-89. Even though the Messier galaxies of the Coma-Virgo Cluster are intrinsically huge and luminous, they are so distant they are hardly good binocular objects. A pair of 7x35s or 7x50s is simply inadequate for these small objects. A good pair of 10x50s will show most of the Coma-Virgo members, although the level of visible detail will be low.

Even with a good star atlas the Coma-Virgo Cluster gives up its treasures only reluctantly to binocular observers. The problem is the lack of bright field stars. My approach is to begin at the 5th-magnitude star 6 Comae Berenices, which is about 7° east of Denebola. About 50′ southeast of 6 Comae (and about 20′ southwest of a magnitude 6.5 star) is the face-on Sc galaxy M-99. Now follow the loose chain of 8th- and 9th-magnitude stars first east and then south to find four faint stars in a group. Just east of this group is the M-84/M-86 pair. M-84 and M-86 are separated by only 20′, and each of them shines at about 9th magnitude. When I first studied this field, both of these galaxies looked like stars, but a couple years later when I examined the Coma-Virgo Cluster in binoculars for the second time, M-84 and M-86 appeared to have nebulous disks.

M-84 and M-86 are both giant ellipticals, each having an absolute magnitude of −21 (about a magnitude brighter than our Galaxy). M-86 is remarkable for having a blueshift instead of a redshift; it is approaching us at a speed of 450 kilometers per second.

When you leave the M-84/M-86 pair, move 1.5° southeast to find the elliptical galaxy M-87. This galaxy is slightly brighter than either M-84 or M-86, and you will have a better chance of seeing M-87 as a fuzzy blob rather than as a slightly out-of-focus "star." M-87 is particularly interesting to astrophysicists because it is a strong source of both radio and x-ray emission and shows a "jet" of ionized matter projecting from the galaxy's center in photographs. (See "M-87: Describing the Indescribable" on page 6 of this issue.) Several other bright galaxies inhabit the region of the Coma-Virgo Cluster. Because you'll have more fun exploring these objects yourself, I'll leave the rest to you.

Most observers, whether newcomers or old hands, will be pleasantly surprised at the number of galaxies visible in ordinary binoculars. On the next clear, dark night pick up a pair of 7x50s or 10x50s, go outside, and see how many of these galaxies you can observe. Remember that spotting them will take a dark sky and a good deal of patience. Once you adjust to finding these little objects in your binoculars, however, you'll come to appreciate gazing at these distant members of the universe every chance you get.

Craig Crossen is an enthusiastic deep-sky observer living in Princeton, Minnesota. His last article, "Studying Galactic Structure with Binoculars," appeared in the July and November 1983 issues.

ASTRONOMY
Reviews

The Universe . . . And Beyond
Terence Dickinson
154 pages, paper, $19.95
Camden House (1986)

What is it like out there? If any one question lies behind most people's interest in astronomy, this could well be it. Shrewdly focusing on that interest, Dickinson says, "My primary goal has been to present the various objects and elements of the universe as they would be experienced by human explorers." I think he succeeds very well, and the result is a book worth having in your library.

It's a handsome thing, printed on glossy paper throughout, and the illustrations (mostly in color) average one per page. You get good value for your money: Besides gathering the best of recent space photos from NASA and the world's major observatories, the book also showcases many imaginative works of space art — scenes of distant planets, where (to steal a phrase) no man has gone before. A few of the space paintings will strike chords of memory among ASTRONOMY readers, but most are new. The reproduction is excellent: even the black and white photos have a depth that eludes many commercial printers.

I mention the illustrations first only because some people will take the book to be just the usual coffee-table snore bought or given on holiday occasions (it appeared right before Christmas). The text is several cuts above that, however. Dickinson is an experienced planetarium lecturer; he also teaches astronomy in a community college. Like all good explainers he has learned how important finding analogies that bring astronomical quantities down into the realm of ordinary human experience is when talking to lay people.

I loved his opening. A car is driving along an empty highway at night, its occupants oblivious to the stars and Milky Way arching overhead. As the car tops a rise, its headlights briefly flick at the sky. In that instant Dickinson follows one lucky photon that escapes being absorbed or scattered in the Earth's atmosphere. As the photon races outward, passing first the Moon, then the planets and, finally, after a few million years have passed, the members of the Local Group of galaxies, we are pulled into the story willy-nilly. It is a deft trick that neatly catches the reader's interest and makes a crucial point about astronomy at the same time.

The sequence of topics that follows is straightforward and conventional: beginning with Earth, we explore the history of the solar system and its planets, moons, and assorted debris. Then we step out farther and examine nearby stars, nebulae, and star clusters. Black holes, supernovae, and all the weird stuff in the astrophysical zoo are covered, of course. Next, it's out into the realm of the galaxies: ellipticals, spirals, irregulars, and clusters of all the above. The following section delves into cosmology, where the illustrative resources (not to mention the imaginations) of various space artists are fully exploited. Maybe "stressed" is a better word.

Last stop, ETI. Dickinson treads a lot of familiar ground here — unavoidable since the field has essentially gone nowhere for the past decade — but these hypothetical ET-scapes are fun to speculate on anyway. (I could have done without the tiresome topic of UFOs, though, as they have nothing to do with real space.) Anyway, the appendices include many tables with simple data on astronomical objects — mass of Barnard's star, diameter of the Milky Way, spin period of Mercury, etc. — and a good list of books and periodicals for learning more.

Books like these have the virtue of making difficult concepts remarkably vivid. They really take you out there, in imagination at least. At the same time, however, this approach has two drawbacks. First, when a concept has been graphically instilled, it resists being changed when new data force us to revise our thinking. For example, years from now when the model for quasars has evolved appreciably, a new version may be more difficult to absorb unless it is presented as strikingly.

Second, and far more dangerous, vivid and detailed illustrations can delude nonmathematical persons into assuming they've gotten a firm grip on a problem. Yet, while mental pictures can provide insights, they are no substitute for a thorough mastery of equations. (Cosmology in particular is a vast pool of quicksand for reasoners-by-analogy.) In the final analysis, however, swapping color for rigor is perfectly acceptable for those of us whose grasp of physics will always remain nonmathematical and who will never be "into" the models the way an astronomer is.

The book is ideally aimed at someone who wants a brightly written, colorful tour of the universe. This could be you or someone you know whose interest in astronomy is just awakening. If there's any problem with the book, it's that the universe found between the book's covers lies a long, long way from the universe seen through a backyard telescope. But of course this warning applies to almost any astronomy book ever written.

The Universe . . . And Beyond is a nicely done, very pretty work that ought to catch at least a few youngsters' imaginations — and maybe yours, too. *Robert Burnham.*

The Astronomical Almanac for the Year 1987; The 1987 Floppy Almanac
Charles K. Roberts and
Alexander Boksenberg, eds.
536 pages, cloth, $25
5¼" floppy disk with documentation
for IBM PC, PC XT, PC XT 286, PC
AT, or DEC MicroVAX II, $20
U.S. Government Printing Office (1986)

The Astronomical Almanac is a compilation of positional and observational data on the Sun, Moon, planets, planetary satellites, asteroids and comets, and stars. It also contains fundamental data on time scales, calendars, coordinate systems, and special astronomical events. With the *Almanac* you can check the positions of planets on any day of the year, determine the end or beginning of twilight for your observing location, plan to observe satellite phenomena such as eclipses of Saturn's moons, find the magnitude of Venus for each day, and locate much more information useful to observers.

The *Floppy Almanac* provides accurate information on the positions of the Sun, Moon, planets, and stars for any date and time within the year; data on the apparent illumination and rotation of the planets; and the times of rise, set, and transit of any astronomical body for any location on Earth. The *Almanac* uses an internal catalog of 200 bright stars, though this catalog can be temporarily replaced at the user's option by any of three auxiliary catalogs included on the diskette: the FK4 catalog of 1,536 bright stars, a catalog of 233 compact extragalactic radio sources, or the Messier catalog. There is also a provision allowing users to establish their own catalogs.

The *Almanac* runs on IBM PC, PC XT, PC XT 286, PC AT, or compatible machines with at least 256k of memory operating under MS-DOS release 2.0 or higher. A separate version makes use of an arithmetic coprocessor and can run up to five times faster, depending on the machine and application. These versions are also available for many portable computers, the DEC MicroVAX, and IBM 370-series mainframes.

Quantum Physics: Illusion or Reality?

Alastair Rae
123 pages, cloth, $29.95
Cambridge University Press (1986)

This book's preface begins by saying quantum physics is "the theory that underlies nearly all our current understanding of the physical universe. Since its invention some sixty years ago the scope of quantum theory has expanded to the point where the behaviour of subatomic particles, the properties of the atomic nucleus and the structure and properties of molecules and solids all are successfully described in quantum terms. Yet, ever since its beginning, quantum theory has been haunted by conceptual and philosophical problems which have made it hard to understand and difficult to accept."

Quantum Physics attempts to sort out the fundamental ideas of quantum physics and the two classic conceptual problems: nonlocality and measurement. Nonlocality means different parts of a quantum system appear to interact with one another even though they are very distant. The measurement problem arises from the assertion that quantum systems possess properties only when those properties are measured, although there is nothing outside quantum physics with which to make a measurement. The following chapters describe various solutions to these fundamental hang-ups, many of which challenge "normal" views of the physical world.

The Unfinished Universe

Louise B. Young
239 pages, cloth, $17.95
Simon and Schuster (1986)

In her foreword Louise Young states: "In every field and woods, in every season of the year we see intricately designed artistic creations — a rosebud opening, a butterfly emerging from a chrysalis, a snowflake drifting on the winter wind. Countless examples speak of an underlying force responsible for designing a world of order and beauty. Yet we cannot close our eyes to the ugliness, the pain, and cruelty that are present, too. . . . How can we reconcile the presence of such evil with the belief in a purposeful and ordered universe?"

In a highly philosophical argument Young attempts to answer this question and sifts through religion, cosmology, biochemistry, natural selection, entropy, and human thought processes along the way.

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Einstein's Dream
Barry Parker
287 pages, cloth, $18.95
Plenum (1986)

The theory of relativity governs the very large scale universe, while the quantum theory controls the very small. For decades physicists have worked to weave these two primary theories of matter into a single, unified field theory. One of the physicists who spent years working on the problem was Albert Einstein. He failed. *Einstein's Dream* recounts physicists' search for a unified physics and describes where it may lead in the future.

Highlights of Modern Astrophysics
Stuart L. Shapiro and
Saul A. Teukolsky, eds.
389 pages, cloth, no price given
Wiley (1986)

In October 1984 astronomers gathered at Cornell University in Ithaca, New York, to hear a series of lectures on nuclear physics, astrophysics, and astronomy, given in honor of the astronomer Edwin S. Salpeter. This volume contains transcripts of these talks, which include presentations by William A. Fowler, Hans A. Bethe, John N. Bahcall, Kip S. Thorne, Riccardo Giacconi, and Philip Morrison.

Was Einstein Right?
Clifford M. Will
274 pages, cloth, $18.95
Basic Books (1986)

Subtitled "Putting General Relativity to the Test," this book examines different facets of general relativity by walking the reader through a series of experiments verifying whether or not claims made by the theory stand up to tests.

A Hundred Billion Stars
Mario Rigutti
285 pages, paper, $9.95
Massachusetts Institute of Technology Press (1986)

This is a revised English edition of the Italian college-level textbook *Cento miliardi di stelle*, first published in Italy in 1978. The first English edition appeared in 1984 and has been revised and made into this new edition.

Gamma-Ray Astronomy
Poolla V. Ramana Murthy and
Arnold W. Wolfendale
248 pages, cloth, $49.50
Cambridge University Press (1986)

Gamma-Ray Astronomy is a technical review of the many subfields that make up astronomy in the gamma-ray part of the spectrum. Chapters cover gamma-ray line astronomy, gamma-ray bursts, medium-energy gamma rays, and ultra-high energy gamma-ray astronomy.

The Voyage of the Ruslan
Joshua Stoff
104 pages, cloth, $12.95
Atheneum (1986)

The Ruslan is an imaginary spaceship built by the Soviets in the 1990s for a manned mission to Mars. This story, based on scientific facts and the possible direction of Soviet technology, is written as if the mission has already occurred. Illustrations are by the author.

Ice Ages: Solving the Mystery
John Imbrie and
Katherine Palmer Imbrie
224 pages, paper, $7.95
Harvard University Press (1986)

What were the ice ages like and why did they occur? A century and a half of ice-age research has given us some answers. This volume covers such factors as Earth's precession, orbital eccentricity, and changes in the planet's magnetic field and climate. The Imbries offer informed speculation on when the next ice age may occur and include climatic forecasts to A.D. 2100 and for the next 25,000 years.

Microcosmos
Lynn Margulis and Dorion Sagan
302 pages, cloth, $17.95
Summit Books (1986)

Microcosmos is a popular-level work on new aspects of the evolution of life on Earth. The authors present evidence for our microbial lineage and about how our very distant ancestors lived and evolved. The authors emphasize the symbiotic nature of those microbes: their affinity for cohabitation and their dependence on one another, which the authors say enabled microbes to survive the dangerous primeval environment. According to the authors, such a view has implications for the survival of the human race.

The Nemesis Affair
David M. Raup
220 pages, cloth, no price given
W. W. Norton (1986)

Serious effort to chronicle current, and not always well-received research into mass extinctions by natural causes is long overdue. Written by a scientist who has done considerable research in this field, this book covers the possible causes of mass extinctions, including a periodic encounter with a faint companion star to the Sun (Nemesis) that gravitationally perturbs comets and hurls them into the Earth, volcanic eruptions that blot out the Sun, and reversals of the Earth's magnetic field. *The Nemesis Affair* is also a self-examination of how "maverick" science research is conducted and received by the scientific community.

Physics of the Sun
Volume III: Astrophysics and
Solar-Terrestrial Relations
P. A. Sturrock, T. E. Holzer,
D. M. Mihalas, and R. K. Ulrich, eds.
287 pages, cloth, $49
D. Reidel (1986)

Broadening the implications of solar research in a series of monographs covering solar physics, the third volume places the Sun in the context of evolutionary models of other stars.

Chaos in Astrophysics
J. R. Buchler, J. M. Perdang, and
E. A. Spiegel, eds.
326 pages, cloth, no price given
D. Reidel (1985)

This is a compilation of a series of papers presented at a workshop on the astrophysical implications of "chaos," the irregular behavior of objects such as variable- and multiple-star systems, magnetic fields, stellar pulsations, and x-ray bursters. Titles include "Cosmic Arrhythmias," "Irregular Stellar Variability," and "X-Ray Bursters — The Hot Road to Chaos?"

Dimensions of Science Fiction
William Sims Bainbridge
278 pages, cloth, $20
Harvard University Press (1986)

Dimensions of Science Fiction is an in-depth study of science fiction and its creators, methods, and social effects. Views from the science fiction subculture are examined by the author and categorized into three competing ideologies. Bainbridge seeks to analyze science fiction as a literature of persuasion, debate, and exploration.

The Second Creation:
Makers of the Revolution
in Twentieth Century Physics
Robert P. Crease and Charles C. Mann
512 pages, cloth, $25
Macmillan (1986)

This book profiles the scientists — past and present — who have participated in the search for a Grand Unification Theory (GUT). The quest for the "Theory of Everything" is told in personal vignettes of the prominent scientists and the lesser known researchers doing the measuring and data gathering that support these GUTs. Crease and Mann discuss in layman's terms the important experiments and intersecting events that have brought physics today to the verge of devising a single theory to explain gravity, electromagnetism, and the strong and weak subatomic forces.

From SU (3) to Gravity
Errol Gotsman and Gerald Tauber, eds.
457 pages, cloth, $59.50
Cambridge University Press (1985)

This is a collection of technical articles and essays that covers topics at the forefront of physical research. The contributions are grouped under five main headings: Groups and Gauges, Particles, Science Policy, Astronomy and Astrophysics, and Gravity and Supergravity.

Medieval Cosmology
Pierre Duhem
Edited and translated by Roger Ariew
601 pages, cloth, $35
The University of Chicago Press (1986)

Drawing from the physicist/historian Pierre Duhem's cosmological discussions, presented in his exhaustive historical work *Systeme du Monde*, which was published in the early 1900s, editor and translator Roger Ariew has compiled a book of cosmological insights. Interestingly, Ariew's assimilation of Duhem's work shows that many of the early cosmological theories strike a familiar chord in modern cosmological theory.

Man in Space:
The First Twenty-Five Years
David Whitehouse, ed.
74 pages, paper, 1.95 British pounds
New Science Publications (1986)

The British science magazine *New Scientist* published this review of international achievements in space to commemorate the twenty-fifth anniversary of spaceflight. Included are articles on Yuri Gagarin's 1961 successful orbital flight, the Moon race, the rescue of Salyut 7, life aboard the Space Shuttle, space stations planned by the United States and the Soviet Union, and the Challenger disaster.

Tools of Radio Astronomy
Kristen Rohlfs
319 pages, cloth, no price given
Springer-Verlag (1986)

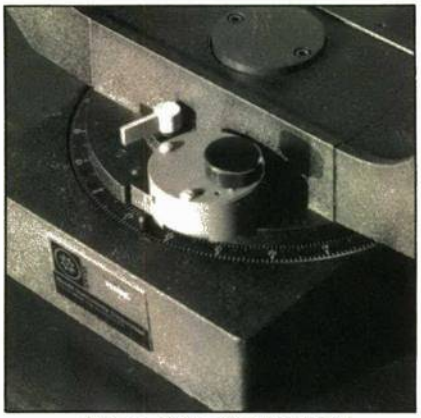
A theoretical textbook on the equipment and techniques needed for research in the radio wavelengths, this advanced book covers the fundamentals of radio astronomy, wave polarization, fundamentals of antenna theory, receivers, interferometers, recombination lines, and radiation from interstellar molecules.

Radiation Hydrodynamics in Stars and Compact Objects
Dimitri Mihalas and
Karl-Heinz A. Winkler, eds.
454 pages, cloth, no price given
Springer-Verlag (1986)

This volume contains the proceedings from a technical conference on hydrodynamics held in 1985 at Copenhagen, Denmark. Among the papers are "The Theory of Protostellar Objects" by Frank H. Shu and "Neutrino Transport in a Type II Supernova Environment" by Paul J. Schnider and Stuart L. Shapiro.

The Amateur Astronomer's Catalog of 500 Deep-Sky Objects, Vol. 1.
Ronald J. Morales
128 pages, paper, $12.50
Aztex Corp. (1986)

The Amateur Astronomer's Catalog is a compendium of telescopic observations of deep-sky objects made with 6-, 8-, and



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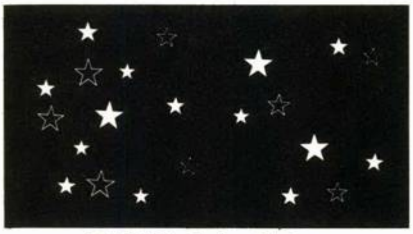

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First in a series of detailed astronomical instructional video tapes by this noted advanced amateur astronomer with 28 years of experience. These are detailed, easily understood video tapes which tell you how to get the most out of your scope so that the hobby gives you less hassle and more fun. The perfect gift for your resident astronomer. Designed for your home VCR, they show the beginner, as well as the more advanced amateur, how to quickly become an expert in the use of Schmidt-Cassegrain Scopes. Some of the subjects covered are: short cuts in set up, how to understand and use setting circles, how to quickly and accurately align with either pole, straight talk about eyepieces and hints on advanced astrophotography. The sequence on optical collimation alone is worth the price. Two tapes now available: #1 Basic SCT operation — $49., #2 Advanced SCT astrophotography — $49. Get both for only $80 and Save $18. Both tapes FREE with each SCT scope we sell!

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Solar System Magnetic Fields
E. R. Priest, ed.
290 pages, cloth, no price given
D. Reidel (1985)

This volume is a compilation of lectures on solar system plasmas, magnetospheric physics, and comet structure. The lectures were given at the Summer School on Solar System Plasmas, held at Imperial College in September 1984.

Luminous Stars and Associations in Galaxies
C. W. H. De Loore, A. J. Willis, and
P. Laskarides, eds.
533 pages, cloth, $94
D. Reidel (1986)

This technical volume contains the proceedings of the 116th symposium of the International Astronomical Union, held in 1985 at Porto Heli, Greece. Among the papers are "The Brightest Stars in Galaxies as Distance Indicators" by Allan Sandage, "Red Supergiants in NGC 300" by John A. Graham and Roberta M. Humphreys, "Systems of Stellar Associations in Galaxies" by Paul Hodge, and "Physical Processes in Massive Star Formation" by Joseph Silk.

Variable Stars
C. Hoffmeister, G. Richter, and
W. Wenzel
328 pages, cloth, no price given
Springer-Verlag (1985)

This comprehensive book, designed for the professional as well as the informed layman, surveys the discovery, dynamics, observation, and classification of variable stars, including pulsating, eruptive, and eclipsing variables. A chapter on the significance of variables in galactic research and stellar evolution is also included.

Annual Review of Astronomy and Astrophysics, Vol. 24, 1986
Geoffrey Burbidge, David Layzer, and
John G. Phillips, eds.
627 pages, cloth, $44
Annual Reviews, Inc. (1986)

The 1986 volume in this review series includes papers on molecules in stars, charge-coupled devices in astronomy, the physics of supernova explosions, mass loss from cool stars, and star counts and galactic structure. The papers are written at a level suitable for third- or fourth-year undergraduates, graduate students, and astronomers reading outside their area of concentration.

Remote Sounding of Atmospheres
J.T. Hoghton, F.W. Taylor, and
C.D. Rodgers
343 pages, paper, $24.95
Cambridge University Press (1986)

Remote Sounding is a series of technical papers on various remote sounding procedures in Earth's atmosphere — temperature, gas pressures, cloud and aerosol measurements, etc. — and remote manipulation of data from Mars, Venus, and the Moon.

First Steps toward Space
Frederick C. Durant III and
George S. James, eds.
307 pages, paper, no price given
ISBN 0-87703-244-0
American Astronautical Society (1985)

One of a series on the history of space flight, this volume reprints many original papers discussing rocketry and propulsion systems in the 1920s and 1930s.

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Mars: Our Future on the Red Planet
Robert M. Powers
230 pages, cloth, $17.45
ISBN 0-395-35371-8
Houghton-Mifflin (1986)

This book explores the possibilities of traveling to or inhabiting Mars in the future.

Galaxies, Axisymmetric Systems and Relativity
M. A. H. MacCallum, ed.
300 pages, cloth, $49.50
ISBN 0-521-30812-7
Cambridge University Press (1985)

This book contains a collection of technical essays on cosmology and physics, presented to the relativistic physicist W. B. Bonner.

Particles and the Universe
G. Lazarides and Q. Shafi, eds.
295 pages, cloth, $40
ISBN 0-444-87005-9
North-Holland Physics Publishing (1986)

These are the proceedings from a 1985 international symposium on particles and their behavior in the universe, held in Thessaloniki, Greece. Included among the papers are "Quantum Cosmology" by A. Vilenkin, "Cosmic Strings and Galaxy Formation" by T. W. B. Kibble, and "The Dynamics of New Inflation" by R. Brandenberger.

The Sun and Solar System Debris
William R. Corliss, ed.
282 pages, cloth, $17.95
ISBN 0-915554-20-8
The Sourcebook Project (1986)
[publisher's address: P.O. Box 107, Glen Arm, MD 21057]

This book is the twenty-second volume in a series that attempts to catalog unusual astronomical and atmospheric phenomena. Included are specific examples of freak or unexplained behavior by various solar system bodies, including comets, asteroids, meteors, and the Sun.

Thunderstones and Shooting Stars
Robert T. Dodd
196 pages, cloth, $24.95
ISBN 0-674-89137-6
Harvard University Press (1986)

Subtitled "The Meaning of Meteorites," *Thunderstones* is a popular introduction to what is known about the remains of space debris that has hit Earth.

Supersymmetry and Its Applications
G. W. Gibbons, S. W. Hawking, and P. K. Townsend, eds.
481 pages, cloth, $49.50
ISBN 0-521-30721-X
Cambridge University Press (1986)

This book contains the proceedings of a workshop on supersymmetry and its applications, held at Cambridge University in 1985. Included among the papers are "Infinity and Anomaly Cancellation in Superstring Theories" by Michael B. Green and "A Fond Farewell to Anti-de Sitter Space" by Daniel Z. Freedman.

Astronomy and Astrophysics
Morton S. Roberts, ed.
383 pages, cloth, no price given
ISBN 0-87168-311-3
American Association for
the Advancement of Science (1985)

This is a technical volume containing a series of essays on the current state of research in solar system, galactic, and extragalactic astronomy. The articles include "Ultraviolet Spectroscopy and the Composition of Cometary Ice" by Paul D. Feldman; "The New Milky Way" by Leo Blitz, Michael Fich, and Shrinivas Kulkarni; and "The Most Distant Known Galaxies" by Richard G. Kron.

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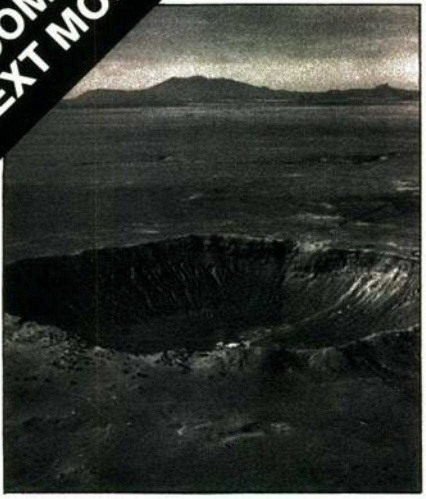
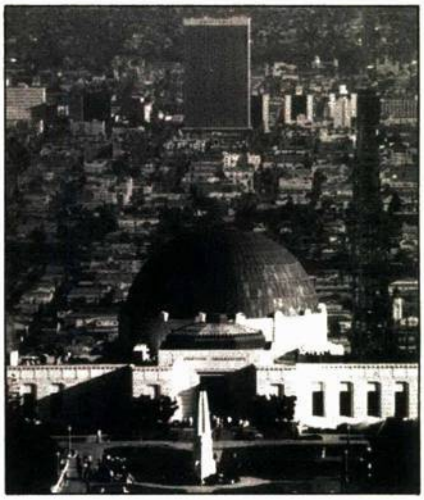
ASTRONOMY's 1987 Summer Travel Guide





That's right! ASTRONOMY's June issue will be your guide to a summer of travel, to visiting exceptional astronomical sites in the U. S. and Canada, to astronomical study and enjoyment, to events where you can meet fellow astronomers!

ASTRONOMY for June will include 22 special pages that will lead you to a variety of interesting astronomical places – from the volcanic slopes of Hawaii's Mauna Kea Observatory to the National Air & Space Museum in Washington, D. C. And you'll find a comprehensive listing of U. S. and Canadian observatories, planetariums, and museums.

Plus, you'll discover a complete calendar of special summer events to attend, a listing of astronomy clubs, and tips on how to enjoy the celestial sights of the magnificent summer night sky.

It's all coming in June ASTRONOMY – don't miss it!

AstroNews

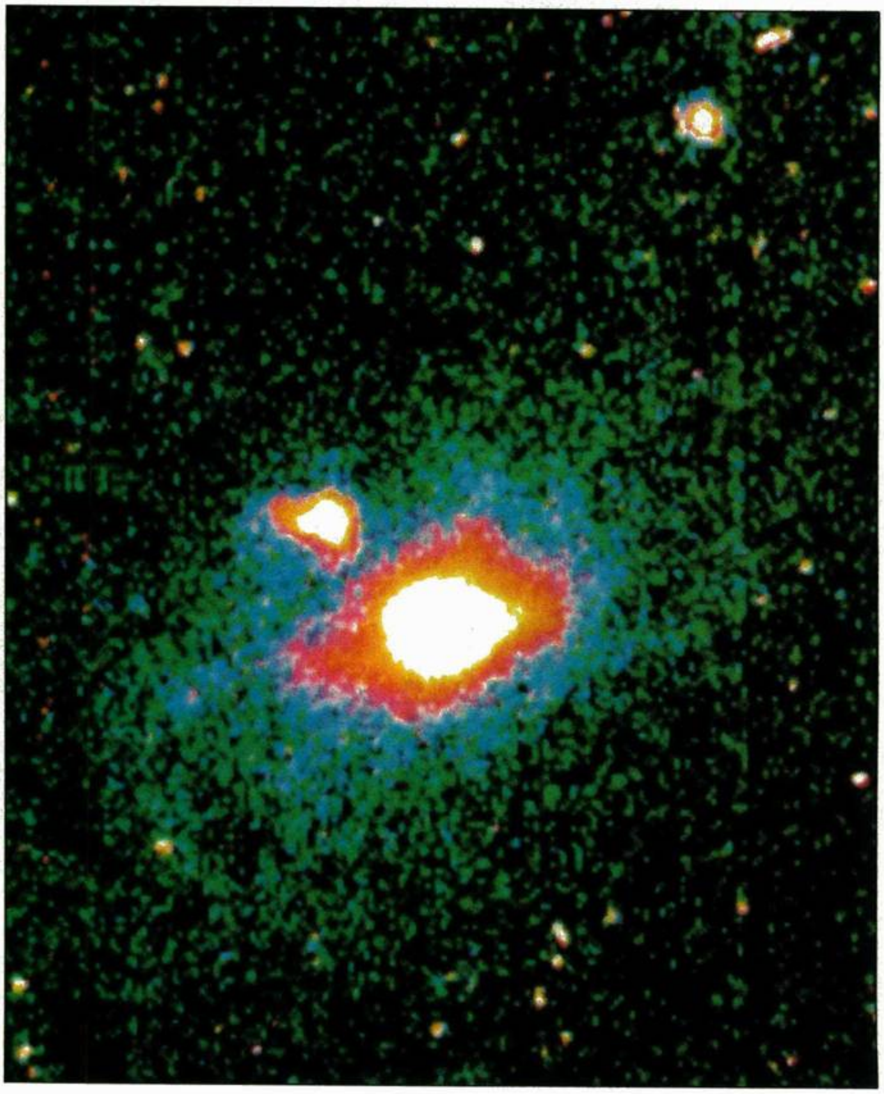
Quasarlike Activity Discovered in Fringes of Radio Galaxy

A group of European astronomers has discovered a gas cloud, associated with the southern radio galaxy PKS 2152-69, that displays both the radiative and spectral characteristics of a quasar. However, most quasars known to exist in galaxies are located at the galaxies' centers, but the quasar activity in PKS 2152-69 is not located in the nucleus but in the galaxy's halo, roughly 9 kiloparsecs from the center.

Quasars are believed to be extremely energetic sources of radiation found at the centers of distant galaxies. In telescopes they look like points of light, but each emits more energy than one hundred supergiant galaxies. A great deal of the quasar's energy is emitted at infrared wavelengths, though quasars emit at all wavelengths and can be strong x-ray sources too. Their intense brightness (many have absolute magnitudes of −27) allows them to be detected from very great distances.

Some of the nearest quasars appear to be surrounded by a "fuzz" that most astronomers believe is a host galaxy too faint to be clearly detected. This supports the theory that quasarlike activity may be occurring in the cores of Seyfert galaxies, though at far less luminous levels. Seyferts are spiral galaxies that have exceptionally bright and energetic nuclei and are strong ultraviolet and x-ray sources.

Although a connection between quasars and elliptical radio galaxies has been implied observationally and theoretically, the distinctions between these two classes of objects are not well delineated. Hence, the discovery of quasarlike activity in the fringes of a *radio* galaxy is of interest to astronomers trying to understand the various evolutionary phases of galaxies.



An energetic gas cloud that displays quasarlike activity has been discovered in the southern radio galaxy PKS 2152-69. In this photo the cloud appears to the upper left of the bright central region of the galaxy. Photo courtesy of the European Southern Observatory.

Situated in the constellation Indus, PKS 2152-69 is a relatively nearby galaxy, lying roughly 15 megaparsecs (500 million light-years) distant. The galaxy exhibits a double-lobed radio structure (two distinct radio-emitting regions) but, because it's deep in the southern sky, it is beyond the scrutiny of present high-resolution radio telescopes.

Images made with special optical filters and a sensitive charge-coupled device attached to the European Southern Observatory's 2.2-meter telescope at La Silla, Chile, clearly show a large cloud about 10 arcseconds from the center of the galaxy.

This cloud is not apparent in unfiltered images.

Spectra of the cloud's light reveal emission lines of highly ionized atoms (Ca^{+4}, Fe^{+6}, and Fe^{+9}), which attest to the extremely high energies in the gas cloud. Such spectral characteristics are normally associated with quasars and extremely active galactic nuclei.

By comparing the intensity of emission in different spectral lines with theoretical calculations, the European astronomers were able to show that the energy source exciting the gas cloud is similar to that responsible for the activity seen in many active galactic nuclei. This suggests that the energy source may also be associated with jets of energetic particles streaming through the galaxy. The astronomers hope that by seeing such nuclear activity well outside the crowded and complex nuclear region, they may get a clearer view of the physical processes operating there.

The discovery was made by C. N. Tadhunter of the Royal Greenwich Observatory, R. A. E. Fosbury of the Space Telescope-European Coordinating Facility, and L. Binette, I. J. Danziger, and A. Robinson of the European Southern Observatory.

Black Hole Candidate Found in M-82

A powerful x-ray source has been discovered in the "starburst" galaxy M-82 in Ursa Major. According to astronomer John Stocke of the University of Colorado at Boulder, the object is a good black hole candidate. The announcement was made at the January meeting of the American Astronomical Society held in Pasadena, California.

The x-ray emissions, said Stocke, are "a factor of ten higher than anything in our Galaxy, and a few factors higher than anything found before." Such x-rays can be generated by matter falling into a strong gravitational field, the kind associated with a black hole. The large x-ray output implies that the binary system has a mass of at least five Suns.

The brightest x-ray sources in our Galaxy are found in x-ray binaries. In such a system gas flows from a normal star toward an unseen, compact companion. As material is drawn into a rapidly spinning accretion disk surrounding the companion, it heats up to the point where it emits copious amounts of both optical and x-ray radiation. Examples of the best determined x-ray binaries in our Galaxy include Cygnus X-3, Centaurus X-3, and Hercules X-1.

Stocke used data from the Einstein Observatory, the first x-ray imaging satellite launched nearly a decade ago. Further data on the x-ray binary system, he says, will require higher resolution observations. But such observations will have to wait until after the Hubble Space Telescope is launched in 1988 or 1989.

The x-ray source discovered in the starburst galaxy M-82 may contain a black hole. Photo by Alfred Lilge.

Dust Clouds Detected around Six Nearby Stars

In the first systematic, far-infrared study of the fifty nearest star systems, astronomers with the National Optical Astronomy Observatories (NOAO) and the University of Arizona report that six stars show signs of circumstellar dust clouds. Such clouds are thought to be the material out of which planetary systems form.

The study was conducted by Dana Backman and Frederick Gillett of NOAO's Kitt Peak National Observatory and Frank Low of the University of Arizona's Steward Observatory. Approximately 80 percent of the stars within 5.2 parsecs (17 light-years) of Earth were studied with data from the Infrared Astronomical Satellite (IRAS) along with infrared observations made at Kitt Peak.

The search detected relatively cool material in orbit around the stars. This material is apparent as an excess of infrared radiation — emissions exceeding those one would expect from the star alone. Such material has already been discovered surrounding more distant stars such as Beta Pictoris (see AstroNews, January 1985) and Vega. Although such clouds typically have temperatures hundreds of degrees below zero, they radiate at wavelengths detectable with IRAS sensors.

The cold infrared excess detected around stars, says Backman, could be interpreted a number of ways. "It could be an interstellar cloud in the background, particles riding outward from a star that is losing mass, or a stellar atmosphere active enough to produce radio and infrared by nonthermal radiation processes. Or — and this is what we think it is in several of these cases — the signal could indicate the presence of particles, remnants of the material from which the star was formed."

Six stars exhibit signs of circumstellar dust clouds:

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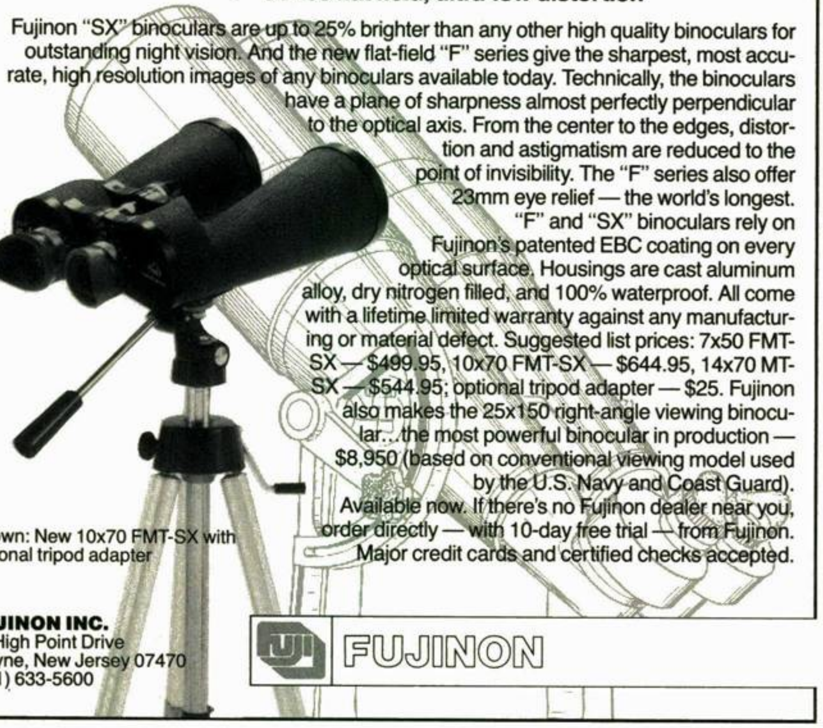

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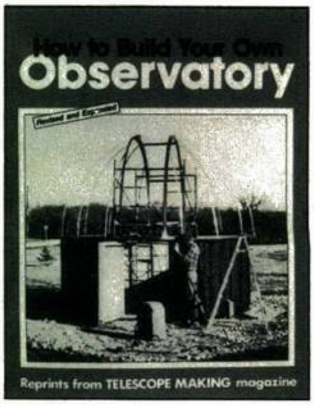

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- Sirius, the brightest star seen from Earth, is not a promising candidate for circumstellar dust, but it does possess an infrared excess. Backman believes the infrared emissions probably originate in the star's atmosphere. It lies 2.6 parsecs distant.
- Epsilon Eridani, 3.3 parsecs away, is the only one of the six already identified as having a dust cloud.
- Ross 128, a single M-dwarf star 3.4 parsecs away, is the best new case for infrared emissions from circumstellar particles.
- 61 Cygni, a binary star 3.4 parsecs from our solar system, contains a dust cloud that may encompass only one member of the pair or could be concentrated around a stable gravitational point in the binary orbit.
- Tau Ceti lies 3.6 parsecs away and is one of the nearest stars most like the Sun. It shows strong indications of a dust shell.
- BD +43° 4305, the most distant star in the study, lies in a "cirrusy" field and emits infrared energy at about the same temperature as that of interstellar dust clouds.

The search for dust clouds around other stars will continue. Backman and his colleagues are currently preparing an "inventory" of star systems showing infrared excesses within a 20-parsec radius.

Comet Mission Not in NASA's 1988 Budget

Start-up funding for a comet rendezvous/asteroid flyby mission (CRAF) has been delayed for at least another year, according to NASA's Fiscal 1988 budget request. Funds for the construction of expendable boosters to supplement NASA's launch capability are also not in the proposed $9.48 billion budget, although plans are under way to switch some Shuttle missions to rocket launches.

The budget proposal NASA initially submitted to the Reagan administration requested $25 million to start the CRAF mission, which was the focus of controversy in late 1985 when NASA dropped the mission's funding from its 1987 budget proposal. The administration, however, rejected the request as well as another new start, the Advanced X-Ray Astrophysics Facility space telescope.

Supplementing NASA's launch capability with expendable launch vehicles (ELVs) is still under study by NASA and, consequently, a funding request is not in the current budget. One Shuttle mission, however, the Cosmic Background Explorer (COBE), will receive funds so it can be refitted for launch on a Delta rocket in 1989 in the 1988 budget. To accomplish this switch, the weight of the COBE craft will have to be reduced by half.

Another mission that may be launched on an ELV instead of the Shuttle is the Mars Observer. In the wake of NASA's

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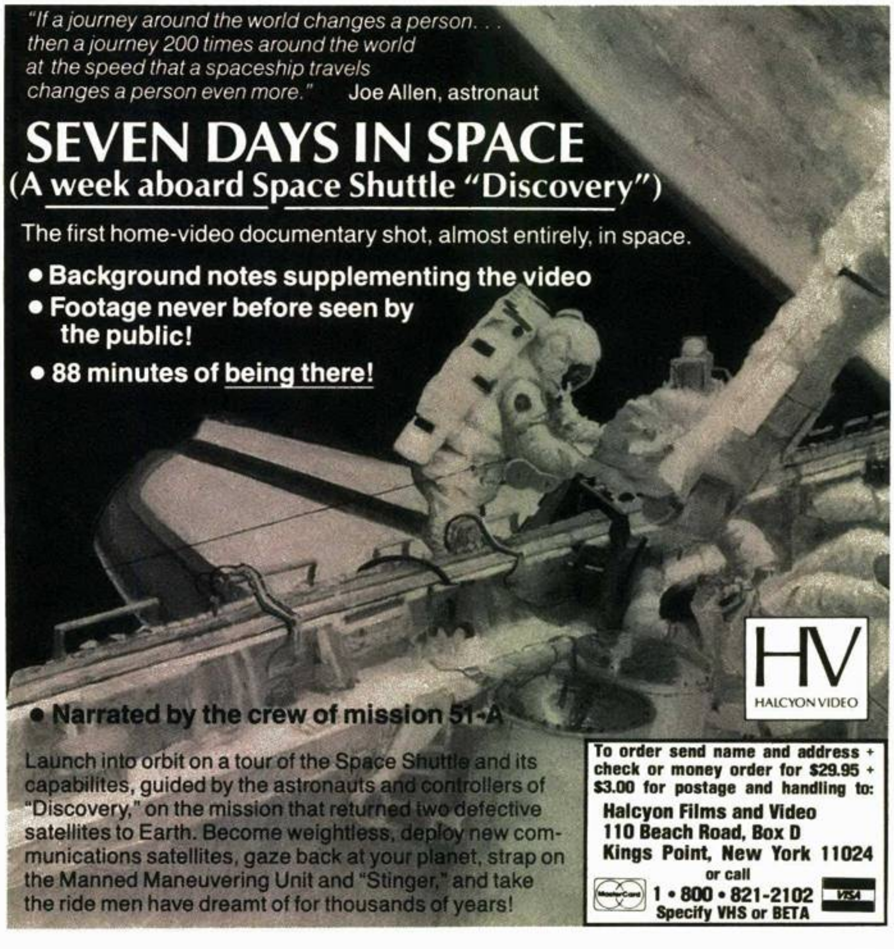

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controversial decision last December to push back the Mars Observer's Shuttle launch from 1990 to 1992, NASA administrator James C. Fletcher has proposed keeping the 1990 launch date by switching the mission to a Titan 34D launcher. Procurement of a Titan, however, depends on additional funding from Congress and negotiations with the Air Force for the rocket.

Super Collider Given Presidential Blessing

The Reagan administration's endorsement in January of the world's most advanced particle accelerator is seen as a boon by particle physicists concerned with keeping the United States at the forefront of nuclear physics research. Supporters of the $4.5 billion project expect the accelerator to enable exploration of the fundamental building blocks of the universe in a way never before considered.

The accelerator, called the Superconducting Super Collider (SSC), would be 87 kilometers in circumference and would utilize 10,000 superconducting magnets to maintain two beams of 20 trillion electron-volt protons on a collision course. The collisions would shatter the protons, creating new subatomic particles that could then be studied.

Researchers expect to be able to explore beyond the current "electroweak" theory, which unifies two of the four fundamental forces of the universe — electromagnetism and the weak nuclear force. The other two forces are the strong nuclear force and the gravitational force. These forces act between elementary particles, which are the basic components of matter in the universe. Physicists are striving to develop a "grand unified theory" capable of expressing the strong, weak, and electromagnetic forces as manifestations of the same phenomenon.

The SSC is expected to be capable of probing distances only one-thousandth the diameter of a proton. This could give physicists some understanding of the structure of matter at that level and perhaps provide further insights into the evolution of the universe.

As part of the presidential budget, the SSC funding legislation must now be passed by Congress. Questions about the project's approval have been raised because of its enormous cost. On the other hand, the project is expected to generate thousands of jobs, and a few states — most notably Texas, California, Illinois, and New York — support the project. Congressional hearings are expected to begin this spring or summer.

ASTRONOMY
AstroCalendar

May 2
Astronomy Day (sponsored by the Wilderness Center Astronomy Club), Wilderness Center, Wilmot, Ohio. Contact: Dave or Robin Gill, 558 Canford Avenue NW, Massillon, OH 44646. Phone: (216) 833-9399.

May 2
Virginia Association of Astronomical Societies Convention (sponsored by the Richmond Astronomical Society), Richmond, Virginia. Phone: 1-800-468-7751 (weekdays).

May 8-10
AstroFest '87 (sponsored by the Broome County Astronomical Society), Roberson-Kopernick Observatory, Vestal, New York. Contact: Roberson-Kopernick Observatory, Underwood Road, Vestal, NY 13850. Phone: (607) 748-3685.

May 8-August 16
"25 Years of Space Photography" 140 photographs taken by unmanned spacecraft; exhibit organized by the Baxter Art Gallery at the California Institute of Technology and sponsored by IBM), International Museum of Photography at George Eastman House, Rochester, New York. Contact: Robert A. Sobieszek, 900 East Avenue, Rochester, NY 14607. Phone: (716) 271-3361.

May 9
Astronomy Day Celebration (exhibits, talks, demonstrations, and a star party sponsored by the Northwest Suburban Astronomers), Hoffman Estates, Barrington, Illinois. Contact: Bob Long, 4960 Chambers Drive, Barrington, IL 60010. Phone: (312) 991-7432.

May 9
14th Annual Astronomy Day. Contact: Gary E. Tomlinson, Astronomical League, Chaffee Planetarium, 54 Jefferson S.E., Grand Rapids, MI 49503.

May 15-18
1987 General Assembly of the Royal Astronomical Society of Canada (annual meeting), Toronto, Ontario. Contact: Steven Spinney, 154 John Tabor Trail, Scarborough, Ontario M1B 2P8. Phone: (416) 281-2392.

May 22-25
19th Annual Riverside Telescope Makers Conference (sponsored by the Riverside Astronomical Society and the San Bernardino Valley Astronomers), Camp Oaks, Big Bear, California. Contact: Cliff Holmes, 8642 Wells Ave., Riverside, CA 92503. Phone: (714) 689-6893.

May 22-24
1987 Conference of the Royal Astronomical Society of New Zealand. Contact: Conference Registrar, 1987 R.A.S.N.Z. Conference, P.O. Box 2241, Wellington, New Zealand, 6000.

May 25-30
Texas Star Party, Fort Davis, Texas. Contact: T.S.P. Registrar, 128 North Commerce, Burleson, TX 76028.

May 30
Hidden Hollow '87 Conference and Star Party (celebrating the thirty-first anniversary of the OTAA, sponsored by the Richland Astronomical Society and the Ohio Turnpike Association), Mansfield, Ohio. Contact: Hidden Hollow '87, The Friendly House, 380 North Mulberry Street, Mansfield, OH 44902.

June 12-13
17th Annual Apollo Rendezvous and Telescope Fair (sponsored by the Miami Valley Astronomical Society and the Dayton Museum of Natural History), Dayton, Ohio. Contact: Robert Sponseller, 2629 Ridge Avenue, Dayton, OH 45414. Phone: (513) 879-5645.

June 22-26
Dark Sky '87 — Visual Astronomy Conference, St. John's College, Santa Fe, New Mexico. Contact: Dark Sky '87, 535 Cordoba Road, Suite 130, Santa Fe, NM 87501. Phone: 1-800-DARKSKY.

June 27
Arkansas Star Party (sponsored by the Ark/Okla Astronomical Society), Douglas C. Coleman Memorial Observatory, Sugarloaf Mountain, Arkansas. Contact: Larry Kennedy, Route 3 Box 421-W, Pocola, OK 74902. Phone: (918) 436-2204 evenings.

July 8-11
5th Cambridge Workshop on Cool Stars, Stellar Systems, and the Sun (review papers and discussions sponsored by the University of Colorado), Boulder, Colorado. Contact: 5th Cool Stars Workshop, CASA, Campus Box 391, University of Colorado 80309-0391.

July 11-12
National Workshop on Teaching Astronomy for Teachers (graduate credit available, offered during the Astronomical Society of Pacific Annual Meeting), Pomona College, Claremont, California. Contact: Andrew Fraknoi, Summer Workshop, A.S.P., 1290 24th Avenue, San Francisco, CA 94122. Phone: (415) 661-8660.

July 11-17
Joint Conference of the Astronomical Society of the Pacific, the Astronomical League, and the Western Amateur Astronomers, Pomona College, Claremont, California. Contact: Andrew Fraknoi, Summer Meeting, A.S.P., 1290 24th Ave., San Francisco, CA 94122. Phone: (415) 661-8660.

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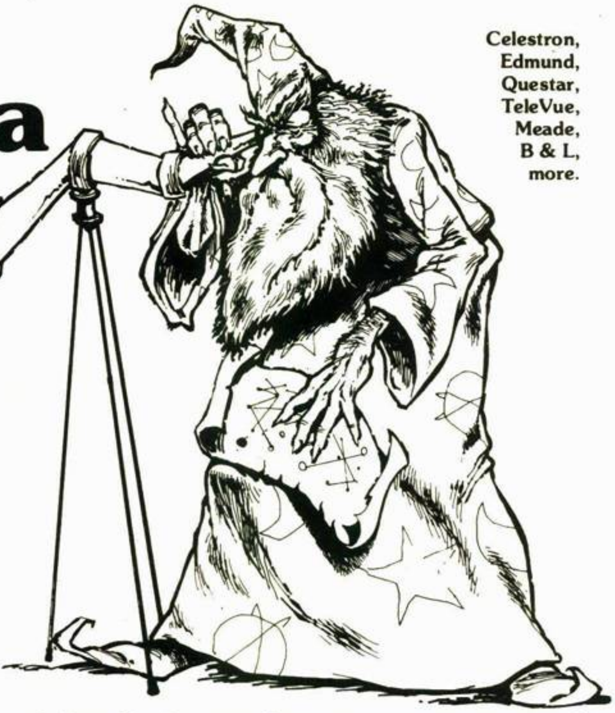

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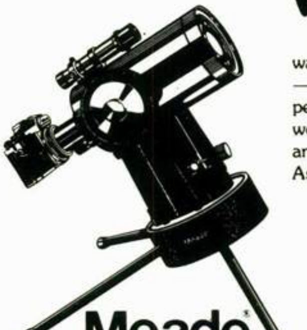

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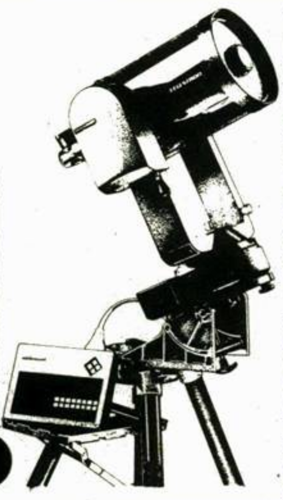

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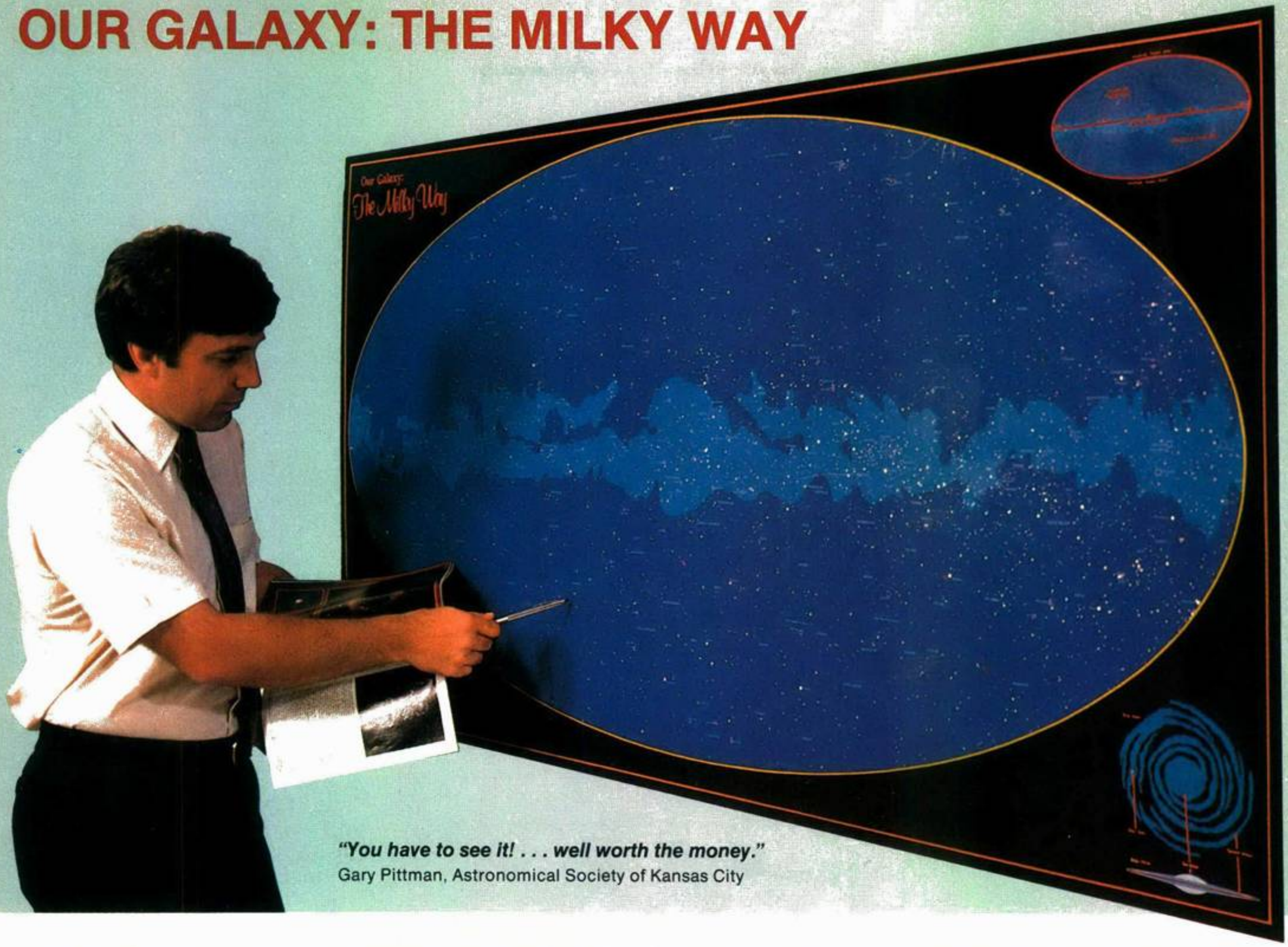

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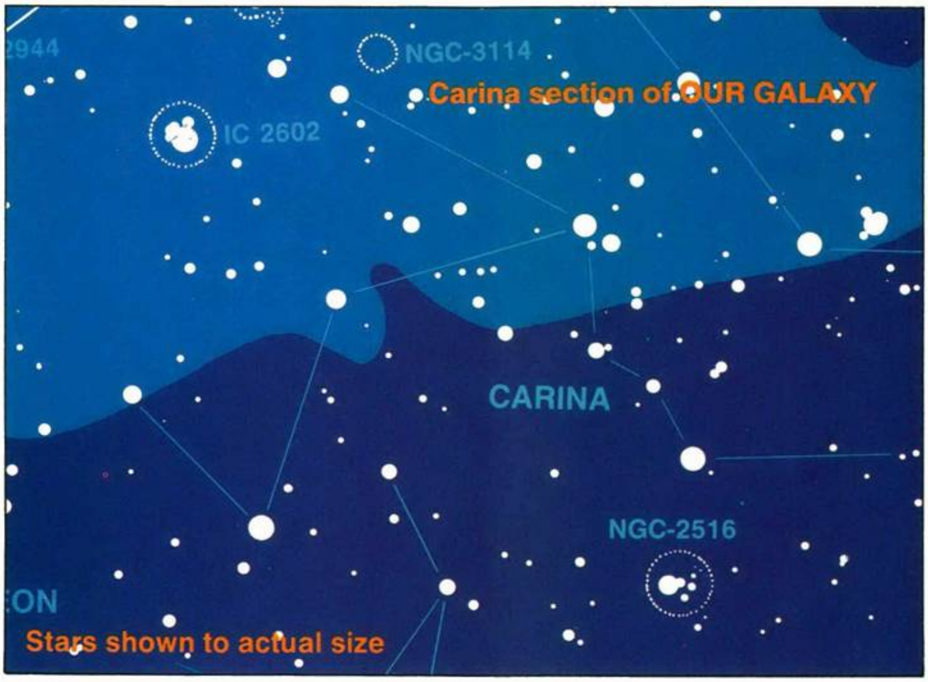

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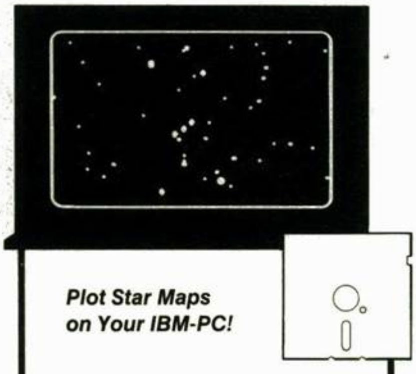

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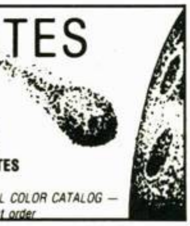

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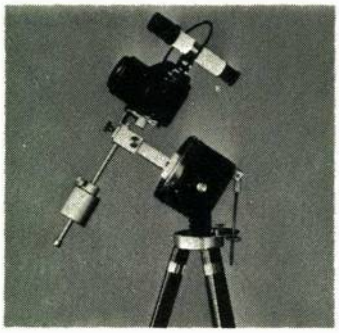

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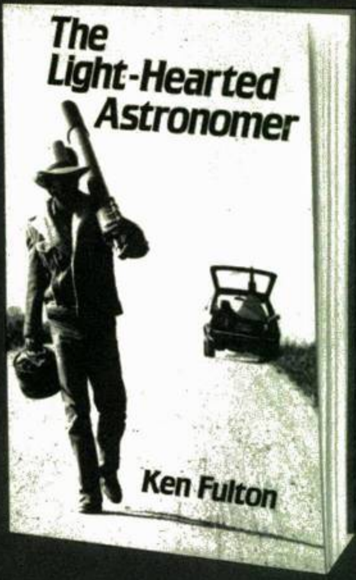

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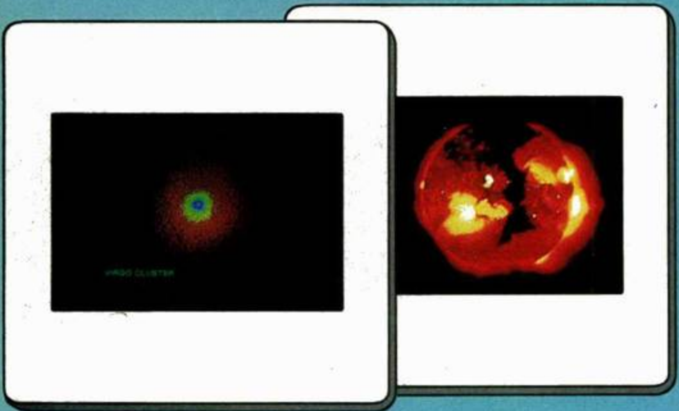

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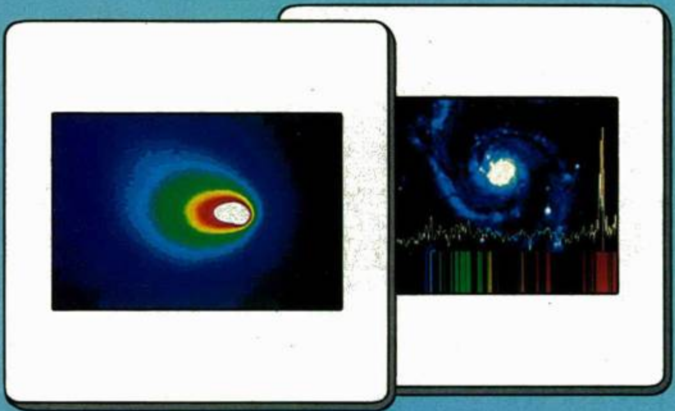

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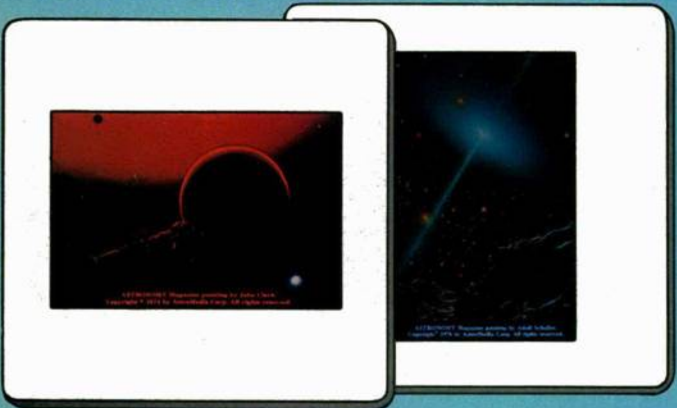

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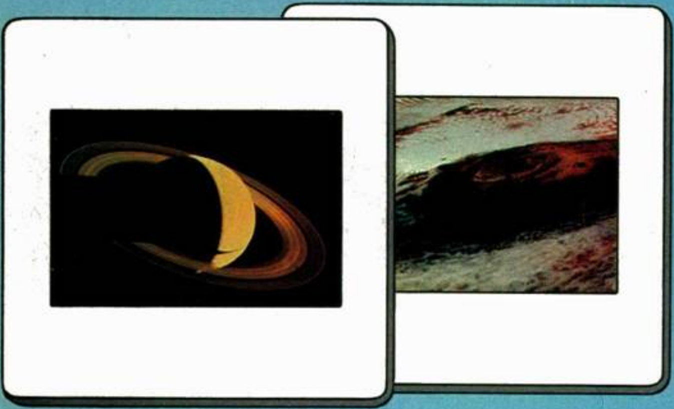

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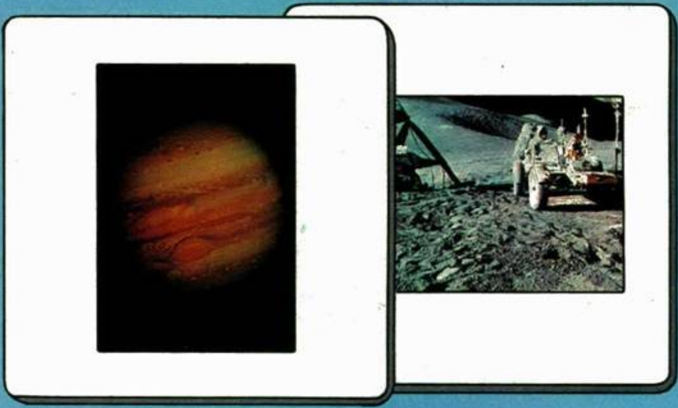

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To the Big Bang and Beyond

by Sten Odenwald

Since the dawn of human awareness mankind has sought an explanation for the origin of the universe. We have grappled with the hows and whys of this event and have seen many ideas spring forth. An ancient Egyptian legend, for instance, describes how the god Osiris Khepera created the universe out of a dark, boundless ocean called Nu, after he had created himself from this ocean by uttering his own name. Human inventiveness has not stood still in the five thousand years since ideas like this originated.

As we contemplate the origin of the universe we find ourselves looking out over a dark, empty void not unlike the one our Egyptian predecessors envisioned. This void is a state of such exquisite perfection and symmetry that it seems to defy description in linguistic terms. Yet physicists and astronomers are probing this void with sophisticated new theories in an attempt to describe not only the moment at which the universe formed but beyond.

The modern theory of the Big Bang states that our universe evolved from a state billions of times hotter than the core of the Sun and trillions of times more dense than the nucleus of an atom. To describe such extreme physical conditions in detail we must first understand the nature of matter and the fundamental forces governing its interaction. At the high temperatures prevailing just after the Big Bang all familiar forms of matter were reduced to their fundamental constituents. The forces of gravity and electromagnetism, together with the strong and weak nuclear forces, were the essential means through which these fundamental particles interacted.

The Limits of Certainty

The physicists' pursuit of a single, all-encompassing theory to describe the four natural forces has, as a by-product, produced some surprising glimpses of the creation event. Although such a theory is still probably several decades from completion, most physicists agree it will have to describe physical conditions so extreme we may never be able to explore them firsthand. Even the particle accelerators being designed today will fall well short of producing the energies required to simulate the earliest history of the universe.

For example, the Superconducting Supercollider planned for the mid-1990s will cost $4.5 billion and will allow physicists to collide particles at energies of 40 trillion electron volts. This will recreate the conditions prevailing just 10^{-15} seconds after the Big Bang. The potential harvest from such an accelerator is enormous and should help answer many questions now plaguing the theoretical community. But to build machines capable of probing to the energies at which the natural forces are fully unified, 10^{19} billion electron volts (GeV), will require far more money and may, in fact, never be practical.

It is curious that the answers to questions such as "What was the early universe like?" and "Do electrons and quarks have internal structure?" should be so inextricably intertwined. And that our ability to find answers to these types of questions does not seem limited by some metaphysical prohibition but by the resources our civilization can devote to the problem. Fortunately the situation is not as bleak as it first seems, because the "machine" has already been "built" and every possible experiment we can ever imagine has already been performed!

What We Think We Know

We are living inside the biggest particle accelerator of all — the universe. Some 10 billion to 15 billion years ago nature conducted an experiment in high-energy physics; the results of this experiment are reflected in the properties and contents of the universe itself. The fundamental facts that characterize our universe are peculiar because they derive from a variety of sources:

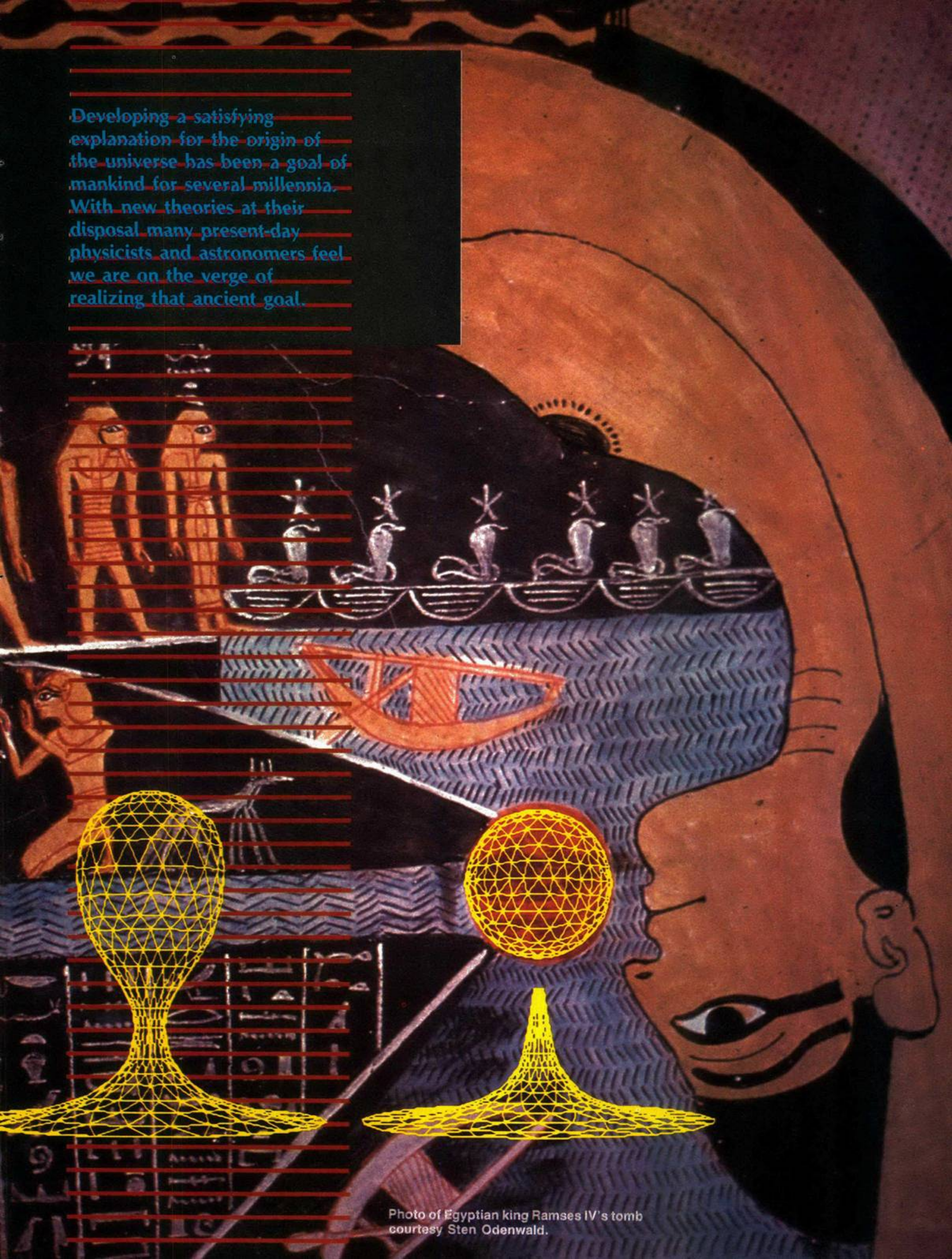
1. We are here; therefore, some regions of the universe are hospitable to the creation of complex molecules and living, rational organisms.
2. Our universe has four big dimensions, which are increasing in size as the universe expands in time and space.
3. There are four dissimilar forces acting in nature.
4. Matter is built out of six quarks and six types of leptons.
5. Matter dominates the universe: no appreciable concentrations of antimatter exist.

Physicists and astronomers are confronted with the task of creating a single theory that is consistent with these facts and that can then be used to derive the secondary characteristics of our universe. These characteristics include the 2.7-degree microwave background radiation, the primordial element abundances, and the existence of galaxies.

A step in this direction is the extension to the standard Big Bang model known as the inflationary universe (see "The Decay of the False Vacuum," ASTRONOMY, November 1983). This theory, developed by Massachusetts Institute of Technology physicist Alan Guth in 1981, combines grand unification theory with cosmology. If it's correct, the theory allows astronomers to trace the history of the universe back to 10^{-35} seconds after the Big Bang when the strong, weak, and electromagnetic forces were unified into a single "electro-nuclear" force. At the time inflationary cosmology was being refined, theoretical physicists continued to search for a way to include gravity in the framework of grand unification theory.

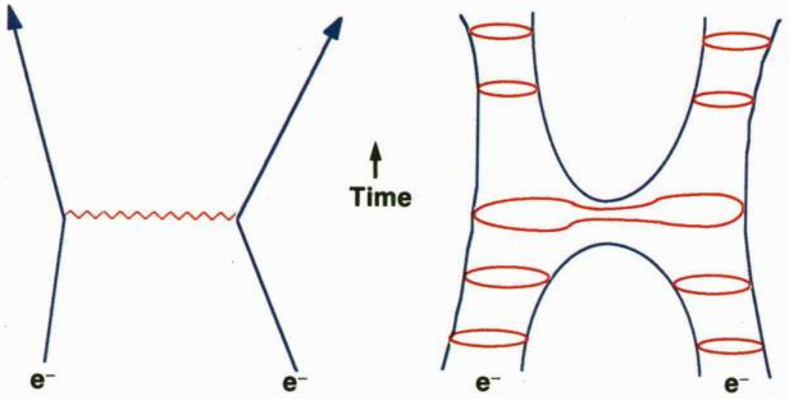
Ten years ago theoreticians developed a new class of theories called supersymmetric grand unified theories (SUSY GUTs). These theories, of which there are several competing versions, may provide physicists with a unified framework in which to describe both the electro-nuclear and gravitational forces, as well as the particles these forces act on (see "The Planck Era," ASTRONOMY, March 1984).

Unfortunately, as SUSY GUTs were studied more carefully,



Developing a satisfying explanation for the origin of the universe has been a goal of mankind for several millennia. With new theories at their disposal many present-day physicists and astronomers feel we are on the verge of realizing that ancient goal.

Photo of Egyptian king Ramses IV's tomb courtesy Sten Odenwald.



Particles and Strings

The interaction of two electrons is viewed differently, depending on the theory used to describe the interaction. In standard particle theory (far left), the electrons approach one another and exchange virtual photons (the wiggly line), causing the electrons to feel the electromagnetic force. The pointlike electrons trace out lines as they travel through space-time. In string theory (left), each electron is represented by a closed loop with a surface that traces out a cylindrical path in ten-dimensional space-time. The string electrons interact by merging and then dividing as they travel through space.

physicists discovered that even the most promising candidates for *the* theory of everything suffered from certain fundamental deficiencies:

1. The predicted number of basic fields was not large enough to accommodate all the known particles.
2. The weak force does not behave as it should.
3. Processes exist that violate the conservation laws of energy and electric charge, among others, which make the theories inconsistent with physical observations.
4. The value predicted for Einstein's cosmological constant is 10^{120} times larger than current observational upper limits suggest.

Theoreticians have made a considerable effort in recent years to circumvent these problems by extending and modifying the postulates of SUSY GUTs. Physicists have long believed that the fundamental particles of matter are pointlike, having no physical size at all. But the best evidence experimental physics can offer is that the electron behaves like a point particle at scales down to 10^{-17} centimeters, which is still an enormous distance compared to the Planck scale of 10^{-33} centimeters, where the unification of the electro-nuclear force and gravity is expected to occur.

One avenue theoreticians have explored questions the legitimacy of this basic premise of previous field theories. Assuming fundamental particles have internal structure, Michael Green at Queen Mary College in London and John Schwarz at the California Institute of Technology have made a remarkable series of discoveries.

Green and Schwarz proposed that if a point particle were replaced by a vibrating "string" moving through a ten-dimensional space-time, many of the problems plaguing SUSY GUTs would vanish. What's more, of all the possible kinds of "superstring" theories, only two were consistent with the principles of relativity and of quantum mechanics, allowed for the behavior of the weak force, and eliminated the anomalies that violated the various conservation laws. Both versions also had 496 different types of fields. Since a particle was associated with each field, there were more than enough fields to accommodate all of the known fundamental particles.

Despite these successes, superstring theories suffer from an important difficulty: the lightest superstring particles are completely massless, while the next more massive particles have masses of 10^{17} GeV. (Physicists often express the mass of a particle in units of the equivalent amount of energy.) It is not even clear how these supermassive string particles are related to known particles, which are virtually massless in comparison (a proton has a mass of only 1 GeV).

If the more attractive of these two theories is destined to be the "theory of everything," there are some additional surprises in store for us. The mathematical properties of this theory imply there may be a totally new kind of matter. This matter, called "shadow matter" by Edward Kolb, David Seckel, and Michael Turner at Fermilab, would be as different from both matter and antimatter as ordinary matter is from antimatter!

Shadow matter may actually coexist with our own more familiar matter and could possibly account for the "missing mass" needed to close the universe. It could only be detected through its gravitational influence, however, because none of the weak, strong, or electromagnetic forces in this shadow world can interact with any of the particles in the normal world.

Beyond Space and Time

The quest for a mathematical description of the physical world that resolves the apparent differences between the known particles and forces has led physicists to a remarkable conclusion: the universe does not inhabit only the four dimensions of space and time, but a much larger arena with many more dimensions (see "Does Space Have More than Three Dimensions?," ASTRONOMY, November 1984). Both the superstring theories and SUSY GUTs agree that our physical world has to have more than the four dimensions we are accustomed to thinking about.

A remarkable feature of superstring theory is that it only leads to a consistent model for the physical world, where all the troublesome anomalies are eliminated, in ten dimensions (nine space dimensions and one time dimension) and not in any other number of dimensions. Physicists now envision six of the ten dimensions as wrapped-up, or "compactified," into miniscule spheres that accompany the four coordinates of every point in space-time.

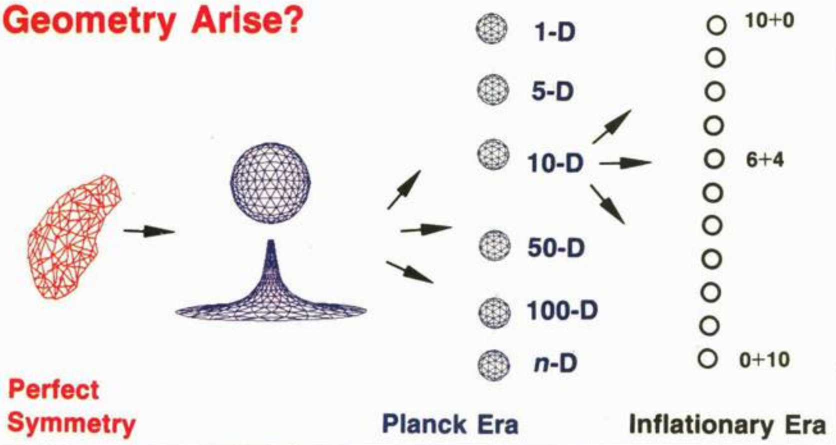
What would a description of the early universe look like from this new viewpoint? Each of the six compact dimensions has a size estimated at roughly 10^{-33} centimeters. If we trace the history of the universe back to very early times, the three large space dimensions eventually shrink until they also approach 10^{-33} centimeters in extent. The nine space dimensions become equivalent when we reach the Planck era, at 10^{-43} seconds after the Big Bang.

What was so special about this era that only four of the ten dimensions grew to their enormous current size? Why not three (two space plus one time) or five (four space plus one time) instead? Physicists have not yet been able to explain this fundamental mystery. On the other hand, a dimensional breakdown of space-time other than '6+4' (six compact and four large dimensions) may just have been totally inhospitable to life as we know it.

As we follow the history of the universe back to the Planck era, there are fewer distinct particles and fewer distinct forces, so the contents of the universe become easier to describe. At 10^{-43} seconds after the Big Bang the universe may have been populated by supermassive particles with masses of 10^{19} GeV, or about 10^{-5} grams each. (Although this is only about the mass

How Did the Universe's Geometry Arise?

There are several possible scenarios for how the universe came to have four large dimensions and six compact ones. One intriguing possibility allows any conceivable type of universe to emerge from the state of perfect symmetry. In this view the ten-dimensional nature of our universe is a product of the Planck era and the specific '6+4' space-time we live in was determined during the inflationary era. An infinite number of universes may exist "out there," each with its own set of fundamental particles and forces, but only a small number of them would look anything like the universe we inhabit.



of a mote of dust, it is truly enormous for an elementary particle.) These particles ultimately decayed into the more familiar quarks and leptons as the universe expanded and grew colder.

In addition, only a single kind of "superforce" may have been acting on these particles. This force encompassed all of the individual attributes we now associate with gravity, electromagnetism, and the strong and weak nuclear forces. Since the particles carrying the superforce had masses similar to those of the coexisting supermassive particles, the distinction between the force-carriers and the particles they acted on probably broke down completely, so the world was fully supersymmetric.

To explore times earlier than the Planck era may require a radical alteration of the conventional way we think about time and space, and the equations and theories of modern physics can only offer glimpses of the appropriate way. In this nascent time all ten dimensions were coequal, at least in terms of physical size. The space-time that emerged from the Planck era is considered the result of the superposition of an infinite number of alternate space-time geometries, a process similar to that which produces interference patterns when light waves combine with one another.

Was there light? Since the majority of photons may not have been created until at least the beginning of the inflationary epoch, 10^{-35} seconds after the Big Bang, it is quite possible that the universe was born out of darkness rather than in a blinding flash of light. All that would have existed in this darkness was the empty space out of which our ten-dimensional space-time later emerged.

As we probe ever closer to the Big Bang, however, it becomes unclear just how we should continue to think about time itself. The theories available today suggest time has a definite zero point, which implies we cannot even speak logically about what happened before time existed. The problem is equivalent to the one facing a traveler standing on Earth's North Pole: he can never move to a position north of his current location! Nevertheless, out of habit we speak of the time before the genesis of the universe and ask, "What happened before the Big Bang?"

Quantum Cosmology

Physicists believe vacuum fluctuations may have played the key role. Vacuum fluctuations are a direct consequence of Heisenberg's uncertainty principle, a fundamental fact of relativistic quantum physics discovered during the latter half of the 1920s. The principle limits how well we can simultaneously know a particle's momentum and location (or its total energy and lifetime).

The fluctuations occur in what we call empty space, or the physical vacuum. (These terms are actually Newtonian fictions, just as absolute space and absolute time are.) Rather than a barren stage on which matter plays out its role, empty space is filled with "virtual particles" that spontaneously appear and disappear beyond the direct detection of any physical measurement. (Despite these ghostly qualities, physicists believe virtual particles exist because they allow a variety of very subtle phenomena to be predicted with amazing accuracy.)

In the early 1970s Ya. Zel'dovich and A. Starobinskii in the Soviet Union and Edward Tryon of Hunter College in New York proposed that the universe emerged from a fluctuation in the vacuum. The lifetimes of the virtual particles created In these vacuum fluctuations depend on the total rest-mass energy of the particles. In such a quantum world less massive virtual particles last longer than more massive ones before Heisenberg's uncertainty principle demands that they vanish back into the nothingness of the vacuum state. Edward Tryon proposed that the universe is just a particularly long-lived vacuum fluctuation differing only in magnitude from those that occur imperceptibly all around us. In essence this vacuum fluctuation ran away with itself and created all the known particles out of empty space at the zero point of time.

The reason the universe has survived so long in spite of its enormous mass is that the positive energy latent in all the matter in the universe is exactly offset by the negative potential energy of the gravitational field of the universe. The total energy of the universe is, therefore, exactly zero, and its maximum lifetime as a quantum fluctuation is enormous and possibly even infinite. According to Tryon, "The universe is simply one of those things that happens from time to time."

In 1978 R. Brout, P. Englert, E. Gunzig, and P. Spindel at the University of Brussels proposed that the fluctuation leading to the creation of our universe started out in an empty, flat, four-dimensional space-time. The fluctuation began weakly, creating perhaps a single matter-antimatter pair of supermassive particles with masses of 10^{19} GeV each. The existence of this first pair stimulated the creation of more particle-antiparticle pairs from the vacuum, which in turn stimulated the production of still others in a self-stimulating, feedback process. As this process continued space became highly curved and eventually exploded, disgorging all of the superparticles that later decayed into the familiar quarks, leptons, and photons.

Heinz Pagels and David Atkatz of Rockefeller University suggested in 1981 that the triggering agent behind the creation event was a change in the energy state of the vacuum. Unlike the Brout-Englert-Gunzig-Spindel model, which started from a flat space-time, Pagels and Atkatz took the complementary approach: that the nothingness from which the universe emerged had a geometry like the two-dimensional surface of a sphere, except that the dimensionality of its surface was much higher than two. As with the previous model this space contained no matter whatsoever. The characteristics (as yet unknown) of the change in the vacuum energy state determined, perhaps in a

The Formation of the Universe

Geometric Representation

Particle Content

Time

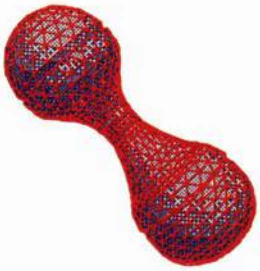
t=0

Perfect Symmetry

Space-time is *n*-dimensional, where "*n*" is undefined if there is perfect symmetry. No particles are present.

t=0

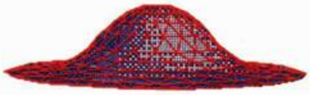
10-D Phase Transition

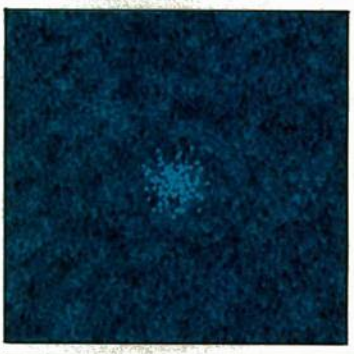


A random fluctuation in the vacuum produces the first particle-antiparticle pair (connected by a wormhole), each with a mass of 10^{19} GeV. When the state of perfect symmetry is broken, the number of space-time dimensions is reduced from *n* to 10.

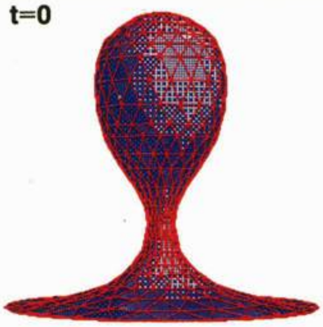
t=0

Quantum Gravity

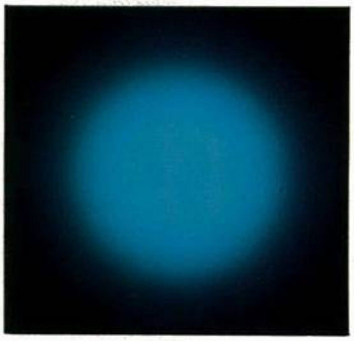




t=0

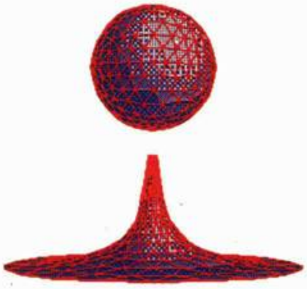


The first particle-antiparticle pair stimulates the production of more supermassive pairs. The ten-dimensional geometry of space-time fluctuates randomly among an unlimited number of possibilities and can only be described in a statistical sense.

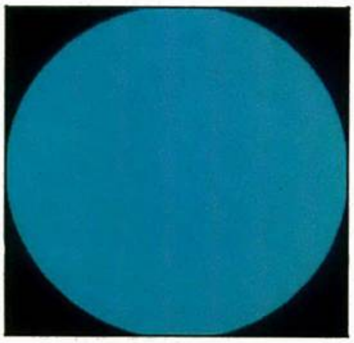


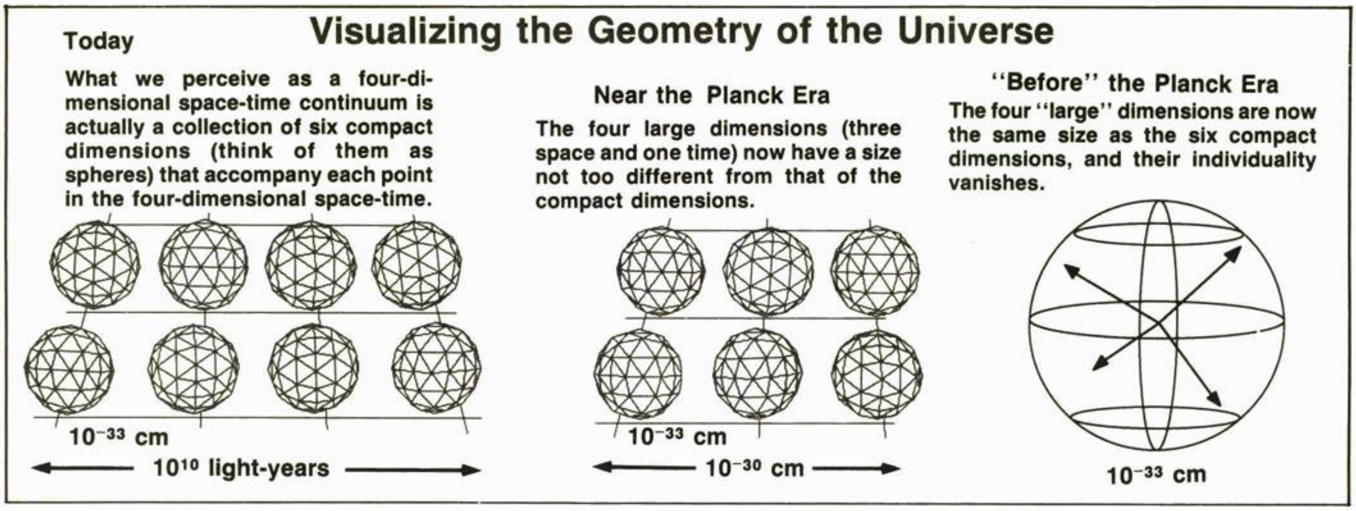
t=10^{-43} sec

Planck Era



The energy state of the vacuum drops to a lower level as the ten-dimensional space-time "buds" to produce a separate universe. This new space-time begins to expand, leading to the '6+4' structure of our universe. The four large dimensions begin to grow as the Planck era ends and the inflationary era begins.





Visualizing the Geometry of the Universe

Today

What we perceive as a four-dimensional space-time continuum is actually a collection of six compact dimensions (think of them as spheres) that accompany each point in the four-dimensional space-time.

Near the Planck Era

The four large dimensions (three space and one time) now have a size not too different from that of the compact dimensions.

"Before" the Planck Era

The four "large" dimensions are now the same size as the six compact dimensions, and their individuality vanishes.

random way, how the dimensionality of space-time would "crystallize" into the '6 + 4' combination that describes our universe.

Alex Vilenkin at Tufts University proposed in 1983 that our space-time was created out of a nothingness so complete even its dimensionality was undefined. And, in 1984, Stephen Hawking of Cambridge University and James Hartle of the University of California at Santa Barbara (UCSB) came to a similar conclusion based on a series of quantum mechanical calculations that describe the geometric state of the universe in terms of a wavefunction. This wavefunction specifies the probability that space-time has any of an infinite number of possible geometries.

A major problem with the standard Big Bang theory is that the universe emerged from a state where space and time vanished and the density of the universe was infinite — a state called the singularity. Hawking and Hartle were able to show that this singularity would become smeared out in space-time because of quantum indeterminacy. In this scenario the universe seems to emerge from a nonsingular state of nothingness similar to the undefined state proposed by Vilenkin. The physicist Frank Wilczek, also at UCSB, expresses this remarkable situation well: "The reason there is Something rather than Nothing is that Nothing is unstable."

Perfect Symmetry

We have seen that SUSY GUTs and superstring theories suggest that the universe was in a highly symmetric state with just one superforce and perhaps one kind of superparticle immediately after the Big Bang. The only thing breaking the perfect symmetry of this era was the definite direction and character of time. To describe the state of the universe before the Big Bang, when the symmetry may have been so perfect that the dimensionality of space was itself undefined, is a daunting challenge in both mathematics and semantics.

The mathematical act of specifying the dimensionality of this state implies the selection of one possibility from among all the others and would thereby break the perfect symmetry. There were, presumably, no particles of matter or even photons of light then because these particles were born from the vacuum fluctuations in the fabric of space-time that attended the creation of the universe. In fact, in such a world nothing at all happens because "happenings" must take place within the reference frame of time and space. The presence of a single particle in this nothingness would have instantaneously broken the perfect symmetry of this era, because then there would have been a point in space different from all others — the point occupied by the particle. This nothingness did not evolve either, because evolution is a time-ordered process. The introduction of time as a favored coordinate would have broken the perfect symmetry too.

It seems that the "trans-creation" state is beyond conventional description, because any words we might choose to describe it are inherently laced with the conceptual baggage of time and space. Heinz Pagels reflects on this earliest stage by saying, "The nothingness 'before' the creation of the universe is the most complete void we can imagine. No space, time, or matter existed. It is a world without place, without duration or eternity."

The scientific literature of the last twenty years suggests physics may be rapidly approaching a major fork in the road. One direction seems to lead to a single theory of everything, unique among all others, because it is internally consistent, satisfies the principles of relativity and quantum mechanics, and requires no outside information to describe the particles and forces it contains. Superstring theory may well be a prototype of this unification theory.

The other direction appears much bleaker. We may create several different theoretical systems, each of which are consistent with everything we know but that contain hard-to-detect flaws. These flaws may stand as barricades to further logical inquiry and can only be razed through experiments beyond our technological reach. Perhaps we are seeing the beginning of this process now with the multiplicity of theories that do not have significant deviations at energies below 10^{19} GeV.

It is very hard to resist the analogy between our current situation and the history of geometry. For two thousand years the basic postulates of Euclidean geometry and the consequences of this logical system remained fixed. Geometry was essentially a closed book: only a few people struggled to find exceptions to it, such as refutations of the parallel-line postulate. Finally, during the nineteenth century, non-Euclidean geometry was discovered and a renaissance in geometry occurred. Are physicists on the verge of a similar great age, hamstrung at the moment because they are unable to devise new ways of thinking about old problems?

Egyptian cosmology was based on motifs the people of that age could see in the world around them: water, sky, land, biological reproduction. Today we still use motifs found in nature to explain the origin of the universe: the geometry of space, virtual particles, and vacuum fluctuations. We can probably expect that our descendents in the centuries to follow will find still other motifs, and from these motifs fashion cosmologies that will satisfy the demands of that future age with much greater accuracy and efficiency than our cosmologies do today. Perhaps the scientists of that future age will marvel at the ingenuity of modern physicists and astronomers, and how in the space of only three hundred years we had managed to create our own quaint theory just as the Egyptians had before us.

Sten Odenwald is an infrared astronomer at the Naval Research Laboratory in Washington, D.C. His last article, "The Road to Discovery," appeared in the August 1985 issue.

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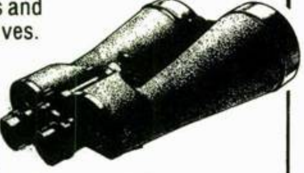

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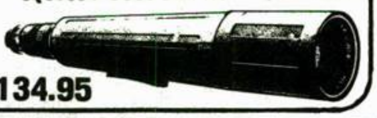

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How to View This Summer's Pluto-Charon Transits

Gazer's Gazette

This spring and summer and for the next three years, whenever the constellation Virgo is visible, astronomers will have the opportunity to observe a remarkably rare celestial event. About every 124 years, on opposite sides of its 248-year orbit, Pluto undergoes a series of eclipses with its moon Charon that are visible from Earth.

An eclipse occurs when Charon's orbit appears edge-on with respect to Earth, which presents transits of Pluto by Charon and its shadow, and occultations of Charon by Pluto and its shadow. During the current opposition Charon will be obscured by Pluto or Pluto's shadow during each passage behind the planet, which gives astronomers a chance to study Pluto without any contribution of light from its moon. Astronomers are watching these mutual events for the very first time, and they won't get another chance to study them again until about the year 2110.

All of this provides exciting opportunities for learning about Pluto. No one knew that Pluto had a moon until 1978, when James Christy of the U.S. Naval Observatory spotted the moon in a photographic image. Because Pluto itself was discovered only in 1930, our awareness of this ninth planet, let alone its satellite and a series of telling eclipses, is a completely modern phenomenon.

Why are astronomers so interested in watching Pluto eclipse its moon and seeing Charon play shadow games on the tiny disk of Pluto? Planetary researchers have a ferocious appetite for bits of data that may help us understand the Pluto-Charon system. Because it is so distant, Pluto typically shines dimly at magnitude 13.7 and appears like a star, showing no disk. Astronomers estimate that Pluto measures about 2,400 kilometers across, has a mass of about 10^{22} kilograms, a rotation period of 6.39 Earth days, is probably composed of water ice and rock, and possibly has a thin methane atmosphere. Charon is thought to be about 1,200 kilometers across and has an orbital period of 6.39 days. This roughly the extent of our knowledge about these two solar system bodies. (See "Pluto: Enigma on the Edge of the Solar System" by Ken Croswell, July 1986.)

Because of this paucity of information about the Pluto-Charon system, planetary scientists will be watching these events for variations in the total light output of the system, which could potentially reveal clues about the fundamental nature of this distant world. For example, information about the albedos, or reflective properties, of the southern hemispheres of both objects could be revealed by observing the magnitudes of the events. Careful examination of the light curves of transits could help to produce a rough surface map of Pluto by indicating light or dark areas on the planet's surface. In addition, timing these eclipses should refine estimates of the diameters, densities, and orbital parameters of the Pluto-Charon system.

Pluto and Charon Facts

	Pluto	Charon
Discovery	Clyde Tombaugh, 1930	James Christy, 1978
Semi-Major Axis	39.44 AU	17,000 km
Revolution Period	247.7 years	6.39 days
Orbital Inclination	17.2°	120°
Orbital Eccentricity	0.250	0?
Obliquity	~65°	?
Rotation Period	6.39 days	6.39 days
Diameter	~2,400 km	~1,200 km
Mass	~10^{22} kg	?
Mean Density	~2,100 kg/m^3	~2,100 kg/m^3
Escape Velocity	~1,270 m/s	~600 m/s
Surface Materials	H_2O ice + dirt?	?
Atmosphere	Thin CH_4?	?

The Pluto-Charon Events

Twenty-nine Pluto-Charon events will occur between May 1 and August 1, 1987, when Virgo sinks below the western horizon as darkness falls. Fourteen of these are called superior events, in which Charon passes behind Pluto and is variously occulted by Pluto or eclipsed by its shadow. The typical magnitude loss for the Pluto-Charon system during a superior event is a mere 0.2 magnitude in blue light. This isn't much: seeing such a small drop in brightness by eye would be exceedingly difficult. We'll rule out the superior events because they're unrealistic targets for backyard observers.

However, the remaining fifteen so-called inferior events, when Charon transits across the face of Pluto and casts a shadow on the planet's surface, are far more easily within the reach of backyard telescopes and typically have a 0.5-magnitude brightness drop in blue light. There are two basic methods for observing the series of inferior events: visually with a medium-size telescope (8-inch or larger aperture) and photographically with either a long telephoto lens piggybacked on a telescope or a telescope fitted with a camera.

One other factor removes a few of these inferior events from the realm of backyard

Pluto-Charon Events for Spring-Summer 1987

Date	First Contact	Second Contact	Maximum Depth	Third Contact	Fourth Contact	Mag.^{B}	Dist. ⊙	Dist. ⊕	Phase Angle	30°N	30°S
May 3 UT	01:08	03:18	03:21	03:23	05:41	0.50	29.69	28.73	0.58°	7:32	8:10
May 22 UT	04:59	—	07:25	—	09:33	0.52	29.69	28.79	0.92°	6:29	8:10
June 4 UT	**23:33**	—	02:03	—	04:07	0.52	29.69	28.89	1.22°	5:26	7:27
June 23 UT	03:25	—	05:59	—	07:56	0.53	29.69	29.10	1.62°	4:01	6:10
*July 6 UT	**22:01**	—	00:33	—	02:29	0.53	29.68	29.28	1.81°	3:09	5:14
July 25 UT	01:54	—	04:24	—	06:20	0.54	29.68	29.57	1.95°	2:05	3:52

*Significant interference from the Moon

Date: Date of event in Universal Time. **First Contact:** Beginning of event in UT; bold face denotes time from previous date. **Second Contact:** Beginning of totality in UT. **Maximum Depth:** Mid-transit in UT. **Third Contact:** End of totality in UT. **Fourth Contact:** End of event in UT. **Mag.^{B}:** Magnitude drop in blue light at maximum depth of event. **Dist.** ⊙: Distance from the Sun in AU. **Dist** ⊕: Distance from Earth in AU. **Phase Angle:** Earth-Pluto-Sun angle in degrees. **30°N:** Window of observing time (with Pluto available and the Sun below −18° elevation) for 30°N latitude in hours and minutes. **30°S:** Window of observing time for 30°S latitude. Note: These times are calculated estimates and may vary by several minutes in actuality.

Table compiled with data from D. J. Tholin, *Astronomical Journal*, **92:**244. Additional sources: R. P. Binzel, *et al.*, *Science*, **228:**1193 and M. W. Pakull and K. Reinsch, *The Messenger*, **46:**3.

observing: nine of the fifteen occur either when Virgo is below the horizon or during the daytime for North American observers. So the list of attractive Pluto-Charon events is narrowed to six between May and August — one about every two weeks. An examination of the circumstances of each of these events reveals which present the best observing opportunities.

May 3 UT: Inferior events are generally not total, because Charon and its shadow are not completely contained within Pluto's projected disk. But there is one exception during this series of events: on May 3, just a few days after Pluto's opposition date of April 29, the size of Charon's shadow will be at a minimum and will therefore cause totality. Charon will transit Pluto's disk on May 3 beginning at 01:08 Universal Time (UT), or 9:08 p.m. EDT on the evening of May 2. (To convert UT into your local daylight time, subtract the following number of hours for each time zone: EDT, 4; CDT, 5; MDT, 6; PDT, 7; Alaska and Hawaii, 9.) The beginning of totality will come at 11:18 p.m. EDT on the 2nd. Maximum depth, the moment when Pluto's image should be 0.5 magnitude fainter than its normal brightness of magnitude 13.7, will be at 11:21 p.m. EDT. Totality, having lasted but five minutes, ends at 11:23 p.m., and the event will be completely over, 138 minutes later, at 1:41 a.m. EDT on May 3. This transit will be visible from eastern Alaska, the United States, Canada, Mexico, South and Central America, Greenland, Europe, and Africa. The Moon will be four days short of First Quarter, so it will be no hindrance.

May 22 UT: May's second Charon transit will begin at 04:59 UT on May 22, which means the event will start at 12:59 a.m. EDT on the 22nd. Since this transit will not be total, there are no second and third contacts. Maximum depth, again a drop of about 0.5 magnitude, will occur at 3:25 a.m. EDT, and the event will be over by 5:33 a.m. EDT. Virgo will set in the west between maximum depth and the end of transit, so observers will see the planet disappear into the horizon glow while the event is still under way. This transit will be visible from eastern Australia, eastern parts of the Soviet Union, Alaska, the United States, Canada, Mexico, South and Central America, and Greenland. The Moon will be two days past Last Quarter, so it will be in the early morning sky only after Virgo has set.

June 4 UT: The first of June's Charon transits will start at 23:33 UT on June 3, which is 7:33 p.m. EDT on the 3rd. Because the Sun will set at about 8:30 p.m., the first part of this event will not be visible. Maximum depth of transit occurs at 10:03 p.m. EDT, and the event ends at 12:07 a.m. EDT on June 4. Again, the maximum light drop-off from Pluto's image will be about 0.5 magnitude. This event will be visible from Canada, the United States, South and Central America, Mexico, Greenland, Europe, and Africa. The Moon will be at First Quarter, contaminating the sky with scattered light throughout the event.

June 23 UT: Charon will transit Pluto's disk again on June 23 beginning at 03:25 UT, or 11:25 p.m. EDT on the 22nd. Maximum depth will occur 2 hours and 34 minutes later, at 1:59 a.m. EDT on the 23rd, when the Plutonian system will be fainter than normal by 0.5 magnitude. The event will end at 3:56 a.m. EDT, after lasting 4 hours and 31 minutes. This transit will be visible from the extreme eastern Soviet Union, Alaska, the United States, Canada, Mexico, South and Central America, and Greenland. The Moon will be three days short of New and therefore completely out of the way during this event.

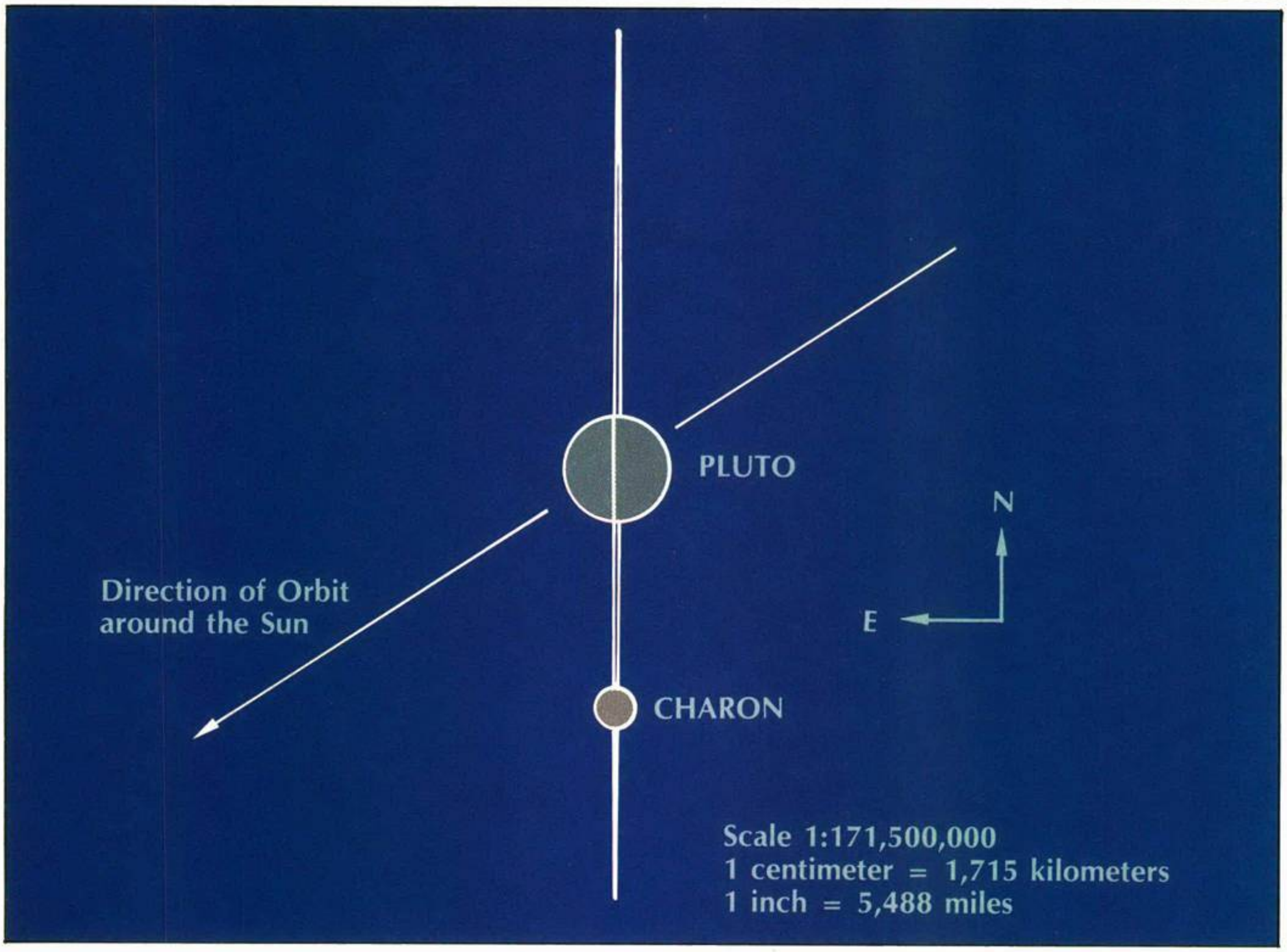
July 6 UT: A transit of Charon on July 6 will be hampered significantly by the Moon, then two days past First Quarter and about 19° southwest of Pluto. The resulting glare will make spotting Pluto difficult, and the event will be over soon after darkness falls. For those who do attempt to find the dim object, July's first event will start at 22:01 UT on the 5th, which corresponds to 6:01 p.m. EDT, before sunset. Thus, the transit will be under way as the sky darkens enough to permit finding Pluto. Maximum depth occurs at 8:33 p.m. EDT, which is still before dusk. The transit will conclude at 10:29 p.m. EDT, after giving observers the chance to see Pluto rise to full brightness. This transit will be visible from the United States, Canada, Mexico, South and Central America, Greenland, Europe, and Africa.

July 25 UT: The final event before August, when Virgo sinks into the western horizon, is a transit of Charon on July 25 UT. This event will begin at 01:54 UT, or 9:54 p.m. EDT on July 24, and Pluto will reach minimum brightness at 12:24 a.m. EDT on the 25th. The transit will end at 2:20 a.m. EDT, which marks the conclusion of the Pluto-Charon mutual events for spring and summer 1987. This transit will be visible from Alaska, Canada, the United States, Mexico, South and Central America, and Greenland. The Moon will be New so it won't pose a problem.

Finding Pluto

Observing the Pluto-Charon events will be tricky and difficult for two reasons. Not only will you have to notice very subtle changes in Pluto's brightness (or record them photographically), but you'll have to find Pluto in the first place, which is no small accomplishment. The prerequisite for finding Pluto, a 14th-magnitude "star" floating in a sea of other 14th-magnitude stars, is a telescope of at least 8 inches aperture and preferably 10 inches.

The Pluto System


PLUTO
CHARON
Direction of Orbit around the Sun
N
E
Scale 1:171,500,000
1 centimeter = 1,715 kilometers
1 inch = 5,488 miles

Observers with 12-, 14-, and 16-inch scopes can still have difficulty locating Pluto.

To hunt down Pluto, set up your telescope and let it cool to the outside temperature for an hour or more while you observe less demanding objects. (This time will allow your eyes to become fully dark adapted, as well.) With your naked eyes, find the constellation Virgo, a large, relatively bright group of stars between Libra and Leo, marked by the brilliant blue-white star Spica (Alpha [α] Virginis). Locate Spica in your telescope's finder scope, and then move about 13° east-northeast. You'll see two 4th-magnitude stars in a north-south line separated by 7-3/4°: Iota (ι) Virginis on the north and Kappa (κ) Virginis on the south. From Iota Virginis move 11° northeast and you'll spy another 4th-magnitude star. This star, 109 Virginis, is the key to finding Pluto during the current season of events. Memorize its location well, because finding 109 Virginis is a step halfway toward finding Pluto.

Now turn your attention to the finder map on pages 100 and 101. 109 Virginis is the bright star near the top of the frame; 5th-magnitude 108 Virginis lies at bottom center. From April 25 to July 29 Pluto will be moving slowly northwest between these stars, then curving sharply to the south, tracing a loop in the sky about three Moon diameters long. To zero in on Pluto, use your finder scope to "star hop" south of 109 Virginis to Pluto's position for the date you are observing. (All dates on the finder map are plotted for 0h UT, so you can subtract the correct number of hours for your time zone and interpolate the position of Pluto to match the correct observing time.)

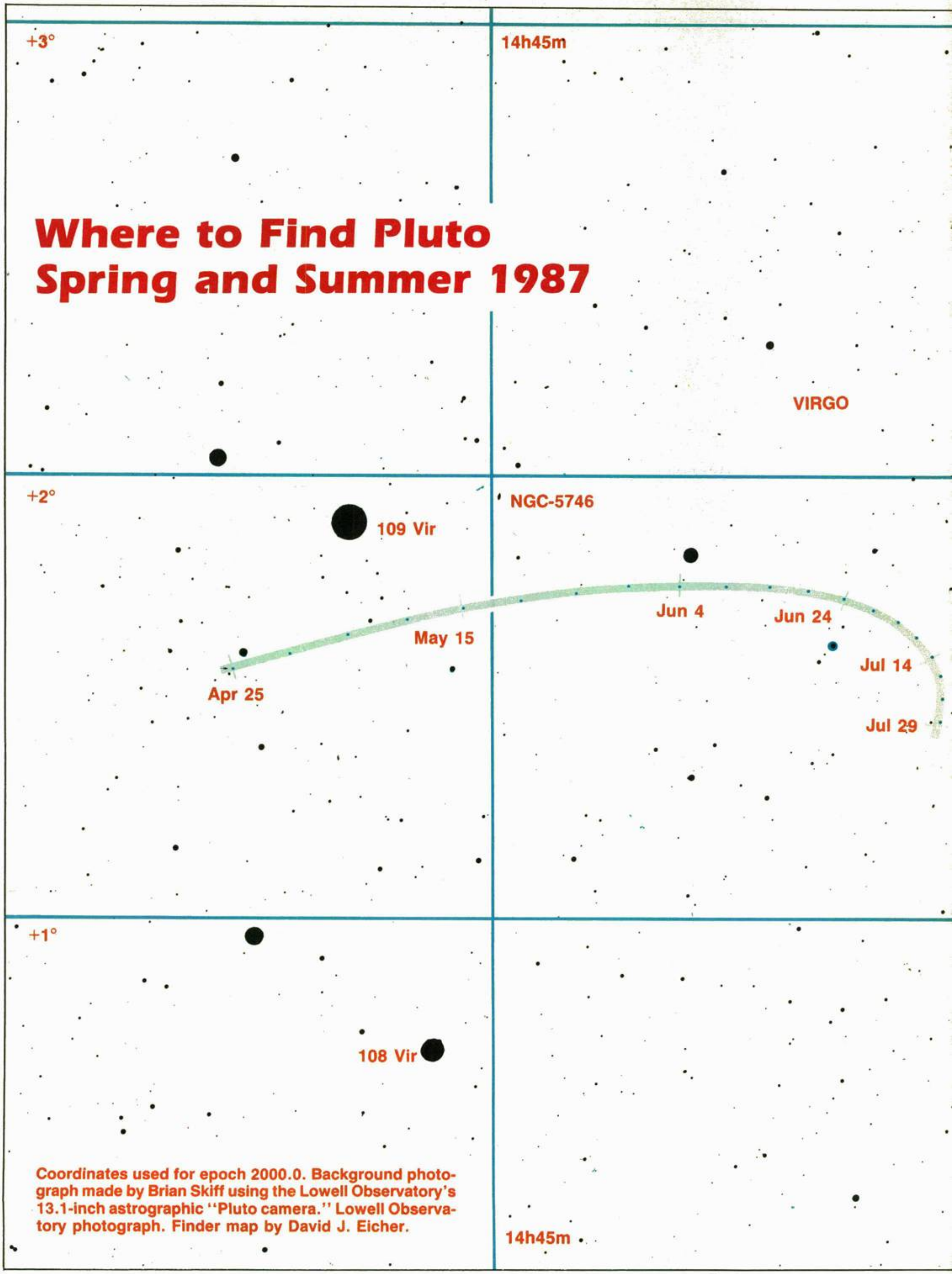
It will be difficult to positively identify Pluto, since there are plenty of stars around 13th and 14th magnitude to confuse with the planet. First, examine the finder chart carefully, matching stars in your eyepiece with those on the chart. You should then be able to identify Pluto. If you are uncertain you've found the planet, make a high-magnification sketch of the region in which you think Pluto lies and retire for the night. Then, one or two nights later, make another sketch. Pluto will have moved slightly relative to the field stars, and you'll be identifying it much the same way observers of asteroids recognize their starlike targets.

Practice finding Pluto and keeping track of its location before the night of an event. You'll have half of the challenge out of the way so you can concentrate on watching Pluto as the event draws near and finally occurs. When you do want to watch an event, center Pluto in your field of view and track it either manually or automatically so that the planet doesn't wander out of the field. Compare in your mind and on paper the brightnesses of other field stars relative to Pluto before the event starts. Then, at the predicted time of maximum depth, carefully re-estimate the brightness of Pluto and compare it with the same field stars you used before. You'll notice that during each of these six events Pluto will fade by half a magnitude and then return to normal as the event ends. Half a magnitude is a very subtle change — subtle enough that an eye unaccustomed to watching stars may not detect it. If you watch Pluto throughout one of these events, you'll be seeing one of the first known showings of this rare Pluto event, and one that, after 1990, won't happen again for 124 years.

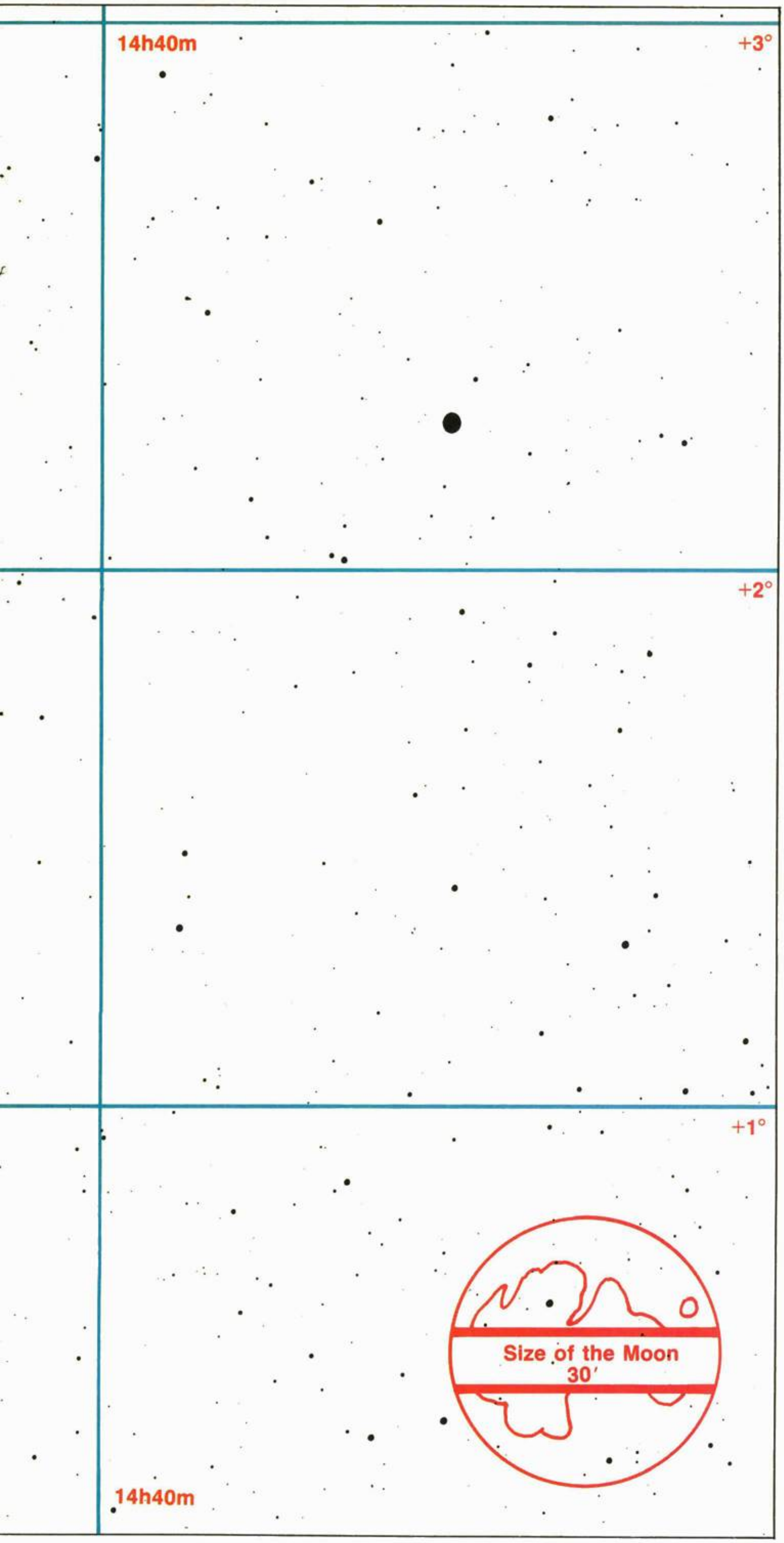
Photographing a Pluto Transit

Much easier than eyeballing the slight visual magnitude drop will be photographing the transits in a series of uniform exposures. The best instrumentation for

Where to Find Pluto
Spring and Summer 1987


+3°
14h45m
VIRGO
+2°
NGC-5746
109 Vir
Jun 4
Jun 24
May 15
Jul 14
Apr 25
Jul 29
+1°
108 Vir
14h45m

Coordinates used for epoch 2000.0. Background photograph made by Brian Skiff using the Lowell Observatory's 13.1-inch astrographic "Pluto camera." Lowell Observatory photograph. Finder map by David J. Eicher.



doing this will be either a long-focus telephoto lens (300mm to 600mm focal length) or a small telescope working at prime focus, like a 6-inch f/8 Newtonian or an 8-inch f/10 SCT. Many films could be used for this type of photography, but hypersensitized Tech Pan 2415 or one of the 1000+ ISO color films will work best. Familiarity with your astrophotographic rig is essential so that you can achieve excellent polar alignment, operate the camera reliably, and track the faint light without trailing it or smearing it out into a blob.

Use the telescope/camera combination for a series of test exposures several days before an event so you can develop the film and check the brightness level of the faintest stars. The objective is to record stars around 14th or 15th magnitude as the faintest objects on the film. As a general rule, if you can capture all the stars on the finder chart, you're recording plenty. (Although it's difficult to generalize because instruments, films, and sky conditions vary, the exposures will probably last between 5 and 15 minutes.)

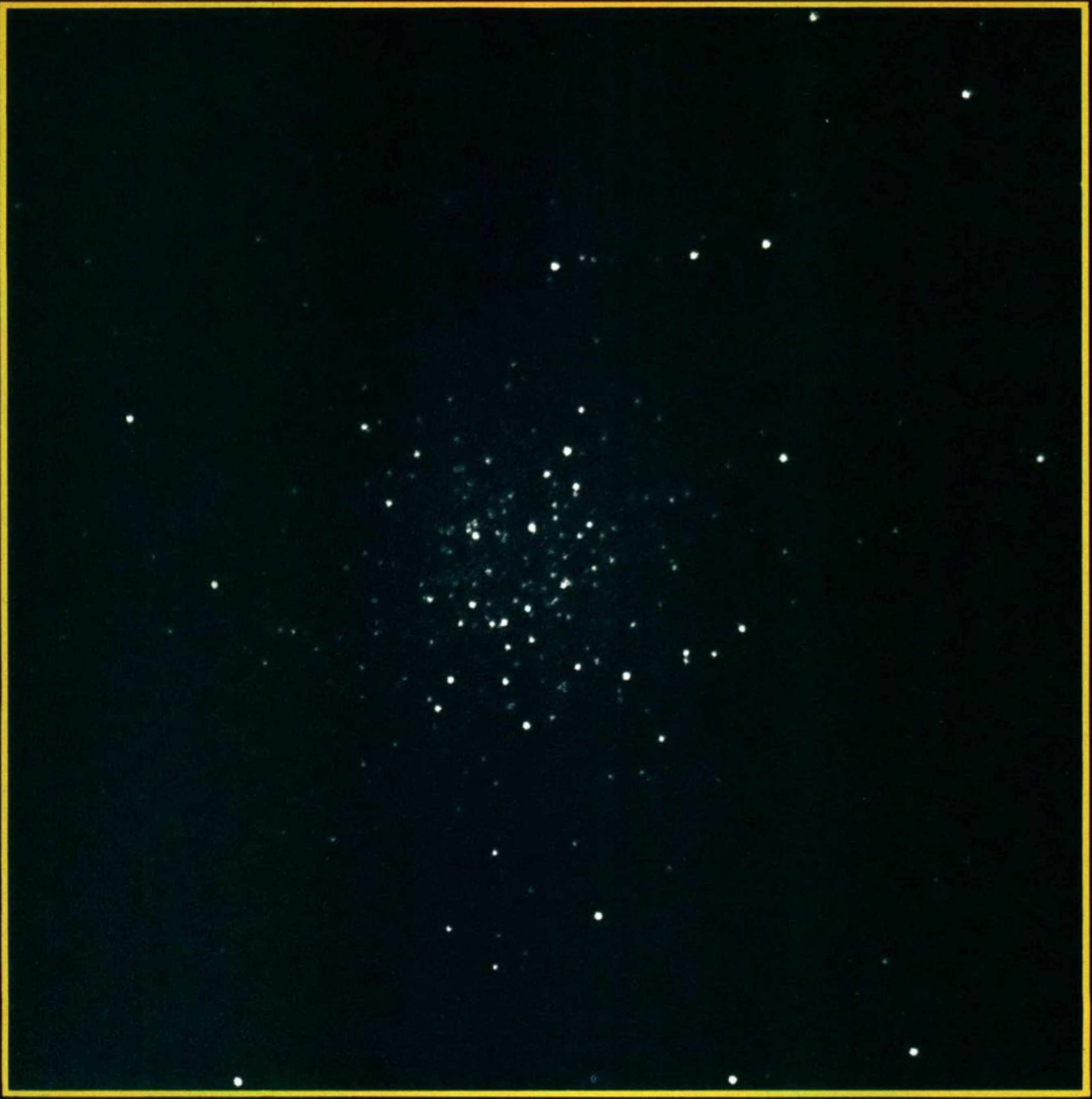
On a night when one of the transits is taking place, set up early and make sure everything is working. Find the Pluto starfield by the same method described in the observing section. Locate a suitable guide star nearby to use during all the exposures. Keep the telescope tracking on that guide star, and you'll be ready for the transit.

Take a series of, say, six to ten exposures at uniformly spaced times to record the gradual fading and brightening of Pluto's image. Make one or two exposures before an event begins as a "normal" image of the Pluto-Charon system. Start another one or two exposures near the beginning of the transit, and make another one or two about one-quarter of the way through the event. The most interesting exposures should be made near the time of maximum depth. These should show the greatest change from the "normal" exposures. Make more exposures three-quarters of the way through, and the final one or two at the end of the event. The result will be a photographic record of a Plutonian transit.

Finding Pluto and observing or photographing one of this season's Pluto-Charon mutual events will undoubtedly take a great deal of patience and observational skill. It will not be an easy undertaking. However, the reward of following our ninth and most distant planet and, for the first time, observing a series of remarkable transits right along with the professionals, will make any observer of the planets glow with pride for years.

— *David J. Eicher.*

The author wishes to thank Richard P. Binzel of the Planetary Science Institute, Edward Bowell of Lowell Observatory, and Robert Marcialis of the University of Arizona for their advice during the preparation of this article.

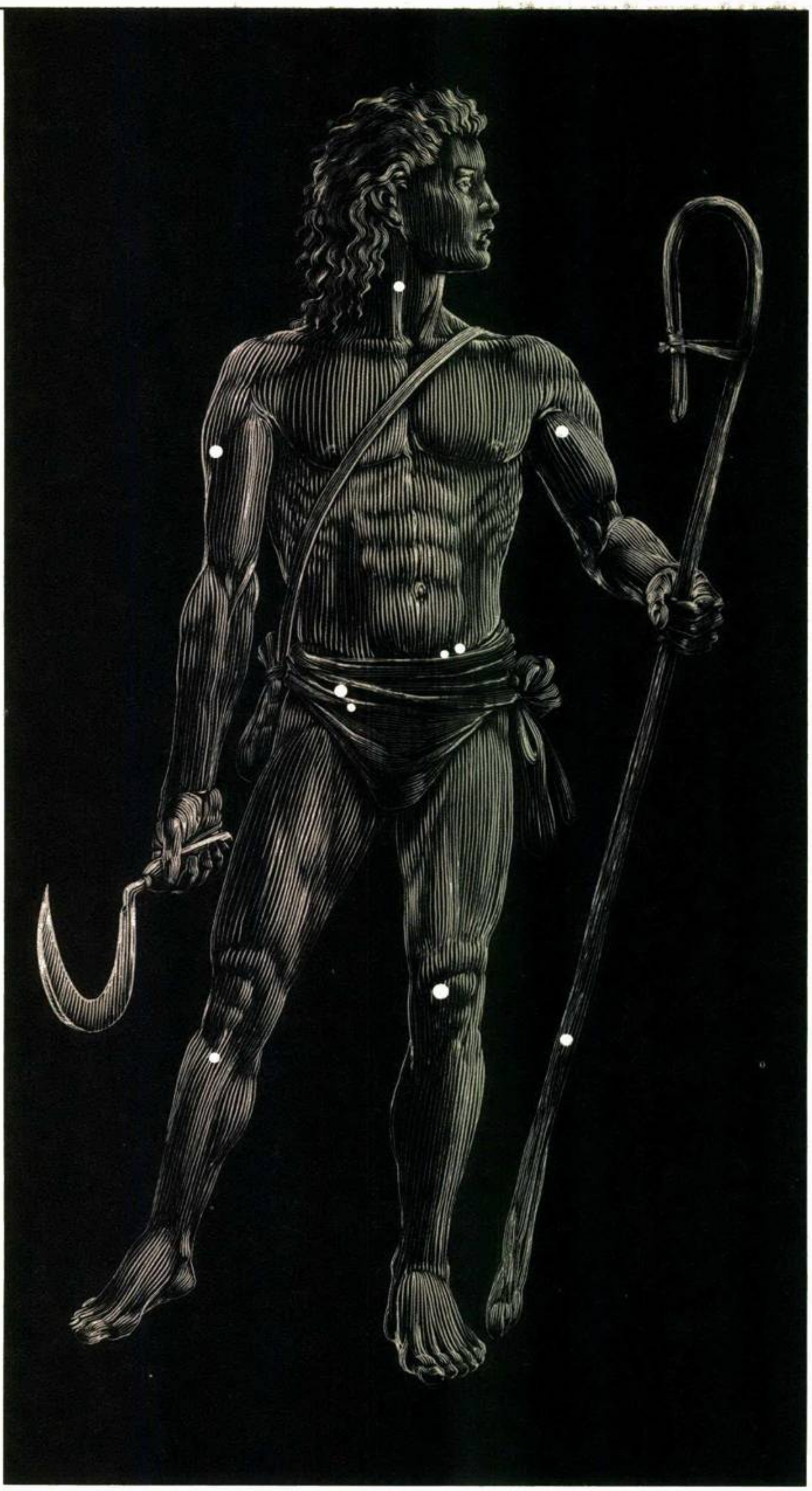


Above: The 9th-magnitude globular NGC-5466 is elusive under poor transparency because of its faint constituent stars. Viewed from a dark, transparent sky, however, the cluster appears like a sprinkling of tiny stars embedded in a nebulous halo. Photo by Martin C. Germano.

Left: The Sc-type galaxy NGC-5248 is visible as an oval-shaped smear of nebulosity in a 4-inch telescope. Lick Observatory photograph.

Bootes

Boo
Bootis



Bootes the Herdsman is a transitional constellation. Surrounded by Milky Way star groups to the northeast, the relative emptiness of the circumpolar sky to the north, and innumerable galaxy fields to the south and west, Bootes isn't classifiable as a constellation rich in either Milky Way or extragalactic goodies. Instead, it has a sprinkling of faint galaxies floating behind a lone globular and a few standout double stars.

The single globular cluster in Bootes is **NGC-5466**, a fairly large object composed of very faint stars. This combination results in a low surface brightness that makes NGC-5466 difficult to spot in telescopes of 3 inches or less aperture. To find this object, begin at Arcturus (Alpha [α] Bootis), and then move 6° north-northwest to the 5th-magnitude star d Bootis. From here move 3° northwest and you'll see a pair of bright stars, 9 and 11 Bootis — 11 to the east and slightly brighter, 9 to the west. The cluster lies 2° northeast of the star 11 Bootis.

A 6-inch scope typically shows this cluster as a 5'-diameter hazy glow without individual stars, although on a night of exceptional seeing some of the brightest of NGC-5466's stars are visible with this aperture. A 10-inch telescope at high power shows a uniformly lit nebulous glow with a sprinkling of tiny glowing cluster members. Larger instruments show progressively more stars, but this cluster remains mostly unresolved in even the biggest backyard telescopes.

Five degrees east of NGC-5466 lies one of the many faint galaxies in Bootes. **NGC-5641** is an S(B)b-type barred spiral dimly glowing with a blue magnitude of 12.9 and measuring 2.7' by 1.6' across. NGC-5641 isn't terrifically impressive in backyard telescopes because it appears like a faint, oval smudge of nebulosity. It does, however, lie in an attractive field containing three bright stars arranged in a triangle, which makes for a pretty sight.

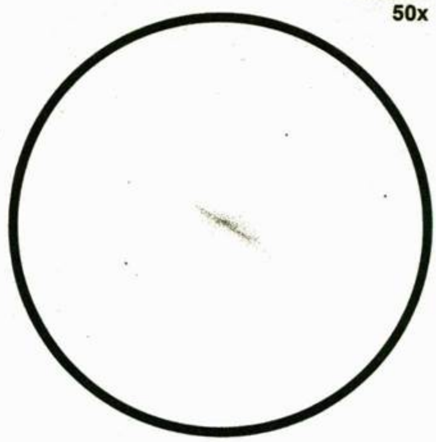
Forming an equilateral triangle with NGC-5466 and NGC-5641 is the faint galaxy **NGC-5523**, which lies 1° east-northeast of the star 12 Bootis. Although this galaxy shines at only blue magnitude 12.9, it is a wonderful object for observers with large telescopes because it is inclined nearly edge-on and is reminiscent of NGC-4565 in Coma Berenices. The galaxy is a type Sb object and measures 4.5' by 1.4' across.

Lying in the extreme southwestern corner of Bootes is the constellation's brightest galaxy, **NGC-5248**. Shining at magnitude 10.2 and spanning 6.5' by 4.9',

For information on naked-eye sky viewing, including planets, constellations, and mythology, see **Eye on the Sky**.

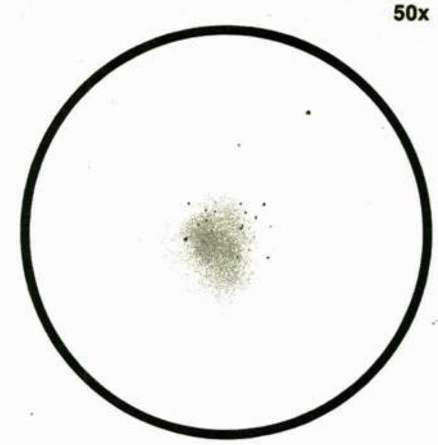
NGC-5248

8-inch
f/10 SCT
50x



NGC-5466

8-inch
f/10 SCT
50x



Sketches by David J. Eicher

this Sc-type galaxy is a fine target for any backyard telescope. A 2-inch scope shows the galaxy as a hazy oval patch of nebulosity without detail. NGC-5248 becomes interesting, however, when viewed with a 6-inch or larger instrument: the galaxy's spiral arms, visible as a faint, elongated haze, surround a bright, round central hub. Large backyard telescopes in the 12-inch to 18-inch class are capable of showing the delicate spiral arms of NGC-5248 on a night of excellent transparency.

About 11° east and a little south of NGC-5248 lies a prominent curved row of three 5th- and 6th-magnitude stars. Move another 3° northeast and you'll come across the amorphous galaxy **NGC-5669**. This galaxy is a type Sc object measuring 4.1′ by 3.2′ and glowing at blue magnitude 12.3. Although it's classified as an Sc galaxy, NGC-5669 appears more like an irregular: a high-power view through a 10-inch scope shows a faint wisp of light streaked over a small, diffuse knot of brighter nebulosity. This object certainly is not impressive, but its visibility may serve as a test of sky conditions.

Back in central Bootes is the spiral galaxy **NGC-5614**, located 2° east-southeast of the 5th-magnitude star A Bootis. This little galaxy glows at magnitude 11.7 and measures 2.7′ by 2.3′ in extent. In a 4-inch scope it appears like a pale disk of nebulosity some 1′ across; larger apertures don't dramatically improve the view.

A fine trio of galaxies — separated from one another by only 1° — lies in northern Bootes. **NGC-5660** lies just 30′ southeast of the 7th-magnitude star g Bootis, and both are visible in a low-power field of view. NGC-5660, an Sc-type spiral oriented more or less face-on, covers 2.8′ by 2.6′ of sky and shines at magnitude 11.8, so it is visible as a fuzzy patch in 4-inch scopes. An 8-inch telescope shows this galaxy to be a moderately bright disk of nebulosity with a brighter central condensation some 30″ across.

Almost 1° to the southeast of NGC-5660 is the much brighter galaxy **NGC-5676**, another Sc specimen. This galaxy shines at magnitude 10.9 and spans 3.9′ by 2.0′, and it appears as an elongated smear of whitish light in small scopes. A 10-inch scope reveals a bright nucleus encapsulated in a milky envelope of grayish-green nebulosity some 2′ by 1.5′ in extent.

Another degree to the southeast is the edge-on barred spiral **NGC-5689**. This galaxy measures 3.7′ by 1.2′ and glows softly at magnitude 11.2. It is visible as an indistinct smudge in a 4-inch scope at moderate power, but to see any noticeable detail in this galaxy, an 8-inch scope is required. An 8-inch instrument reveals NGC-5689's tiny, bright nuclear region and a thin strip of faint nebulosity running through it and extending for 1′ on both sides.

Northeastern Bootes holds two more galaxies for backyard telescopes. **NGC-5820** is a 12th-magnitude elliptical galaxy lying only 15′ west of a 7th-magnitude double star. The galaxy is visible as a round nebulous patch of light measuring some 2.5′ by 2.3′ across. About 12° south-southeast of NGC-5820 is **NGC-5899**, lying about 15′ southeast of a lone 7th-magnitude star. This Sb-type spiral shines at magnitude 11.8 and measures 3.0′ by 1.3′ across. It appears as an elongated blotch of nebulosity with a slightly condensed core in small backyard telescopes.

Bootes offers three impressive double stars for users of small scopes. The first of these, **Xi (ξ) Bootis**, lies some 9° east of Arcturus. Composed of magnitude 4.7 and 7.0 stars separated currently by 8.0″ in p.a. 230°, Xi Bootis is easily split by any telescope at reasonably high magnification. Its stars are, in the words of Thomas W. Webb, "clear yellow and reddish purple."

More challenging is the brighter star **Epsilon (ε) Bootis**, part of the kite-shaped asterism that forms the central figure of Bootes. Epsilon Bootis is made up of magnitude 2.5 and 4.9 stars separated by 2.8″ in p.a. 339°. The components are far enough apart that almost any telescope can split them with high power, and the colors are yellowish-orange and blue.

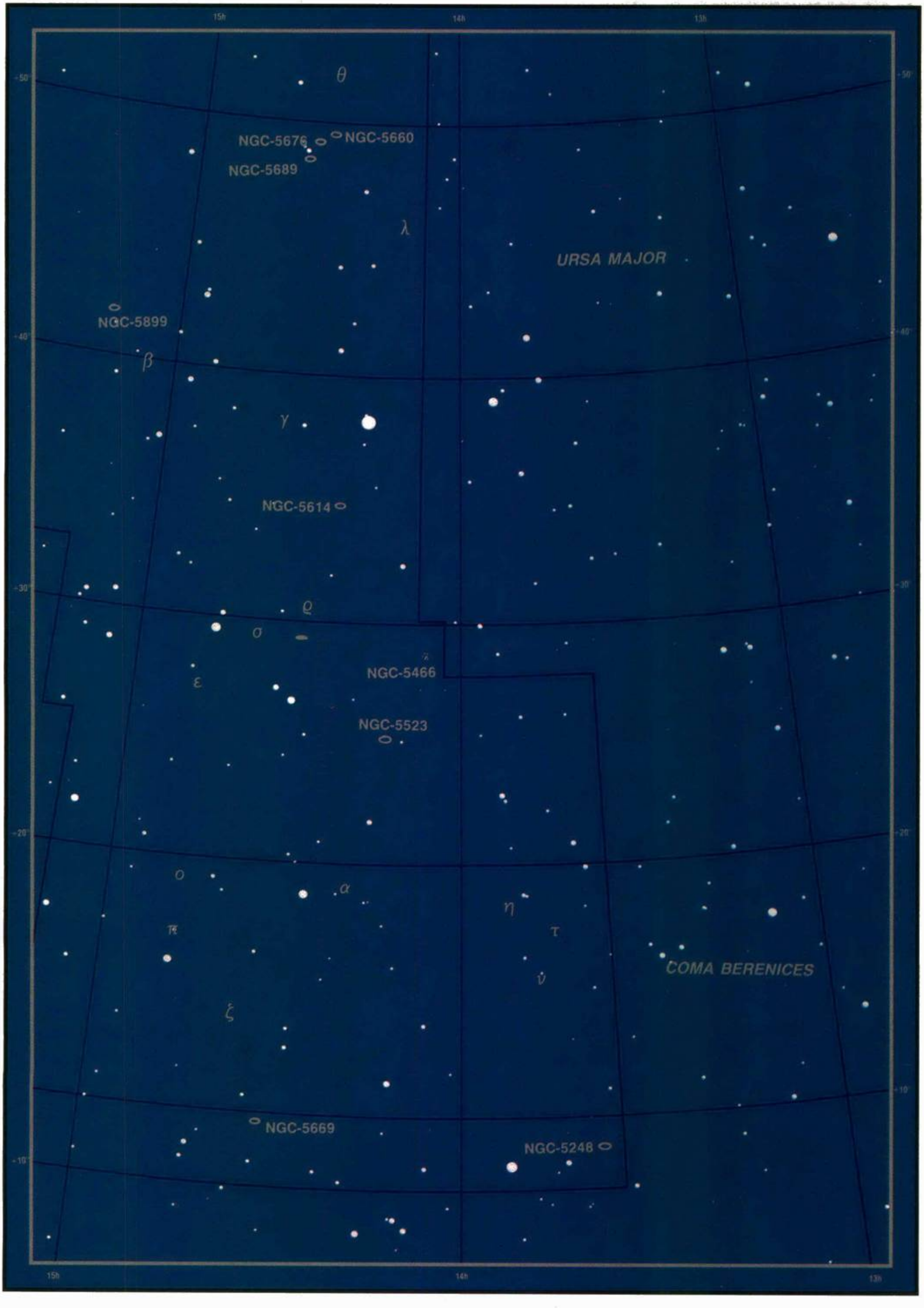
In northeastern Bootes lies the 5th-magnitude double star **i Bootis**, also known as 44 Bootis. This star contains magnitude 5.3 and 6.2 components currently split by a mere 1.6″ in p.a. 220°. The colors are yellow and blue.

Object	M#	Type	R.A. (2000)	Dec.	Mag.	Size/Sep./Per.	H
NGC-5248		§	13h 37.5m	+8°53′	10.2	6.5′x 4.9′	Sc
NGC-5466		●	14h 05.5m	+28°32′	9.1	11.0′	
NGC-5523		§	14h 14.8m	+25°19′	12.9_B	4.5′x 1.4′	Sb
NGC-5614		§	14h 24.1m	+34°52′	11.7	2.7′x 2.3′	S
NGC 5641		§B	14h 29.3m	+28°49′	12.9_B	2.7′x 1.6′	S(B)b$^-$
NGC-5660		§	14h 29.8m	+49°37′	11.8	2.8′x 2.6′	Sc
NGC-5669		§	14h 32.7m	+9°53′	12.3_B	4.1′x 3.2′	Sc
NGC-5676		§	14h 32.8m	+49°28′	10.9	3.9′x 2.0′	Sc
NGC-5689		§B	14h 35.5m	+48°45′	11.9	3.7′x 1.2′	SBa
Epsilon (ε)		★^{2}	14h 45.0m	+27°04′	2.5,4.9	2.8″	
Xi (ξ)		★^{2}	14h 51.4m	+19°06′	4.7,7.0	8.0″	
NGC-5820		0	14h 58.7m	+53°33′	11.9	2.5′x 2.3′	E5
i		★^{2}	15h 03.8m	+47°39′	5.3,6.2	1.6″	
NGC-5899		§	15h 15.0m	+42°03′	11.8	3.0′x 1.3′	Sb$^+$

★^{2}	*Double Star*
●	*Globular Cluster*
§	*Spiral Galaxy*
§B	*Barred Spiral Galaxy*
0	*Elliptical Galaxy*

H = Hubble type for galaxies

Subscript "P" denotes photographic magnitude; subscript "B" denotes blue magnitude.


15h
14h
13h
+50°
+40°
+30°
+20°
+10°
θ
NGC-5676
NGC-5660
NGC-5689
λ
URSA MAJOR
NGC-5899
β
γ
NGC-5614
ϱ
σ
NGC-5466
ε
NGC-5523
ο
α
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π
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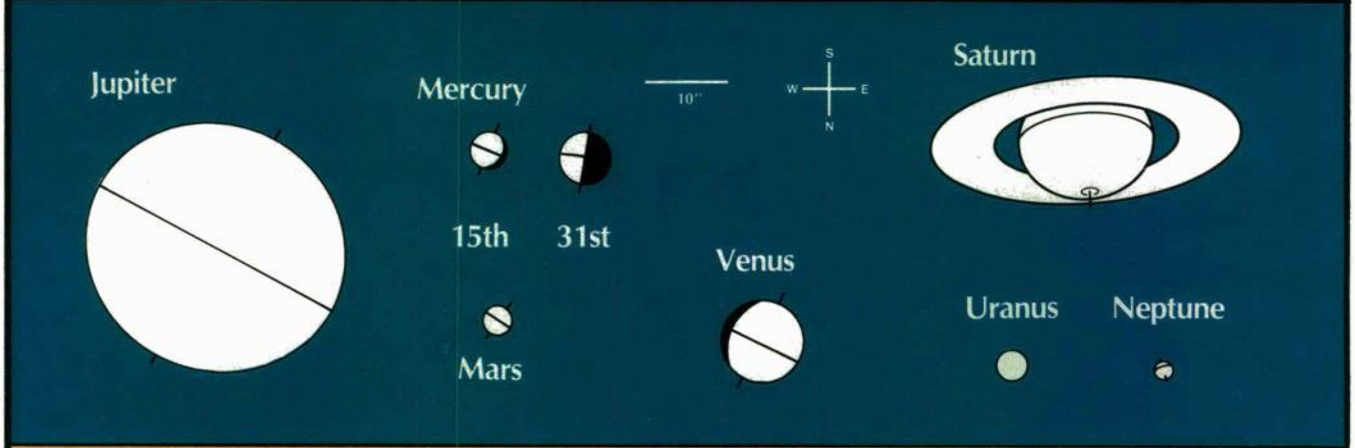
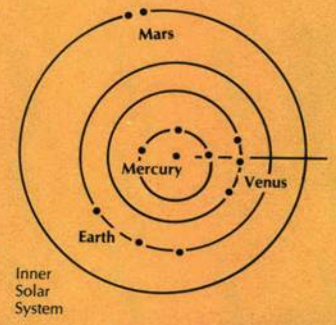
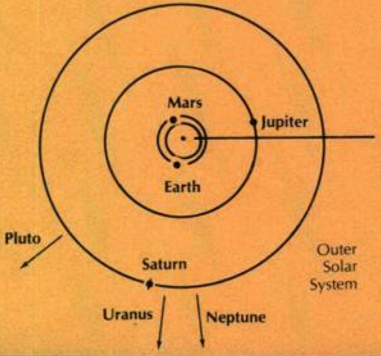
ν
COMA BERENICES
ξ
NGC-5669
NGC-5248

Planetary Data May 1987


Jupiter
Mercury
15th
31st
Mars
10″
S
W
E
N
Saturn
Venus
Uranus
Neptune

		Date	Mag.	Angular Size	% Illum.	Distance (AU) from: Earth	Sun	Longitude: Heliocentric	Ecliptic	R.A. (2000.0)	Dec.
Sun		1	−26.7	31.8′	—	1.007	—	—	40°06.7′	2h 31.5m	14°54.3′
		15	−26.7	31.7′	—	1.011	—	—	53°39.5′	3h 25.8m	18°44.0′
		31	−26.7	31.6′	—	1.014	—	—	69°02.7′	4h 30.1m	21°50.2′
Mercury	☿	1	−1.4	5.1″	96%	1.316	0.343	10°35.4′	32°58.3′	2h 04.3m	11°26.1′
		15	−1.5	5.3″	93%	1.263	0.310	93°35.5′	62°51.6′	4h 02.1m	21°55.8′
		31	−0.1	7.0″	54%	0.965	0.348	177°20.6′	91°13.6′	6h 05.9m	25°36.0′
Venus	♀	1	−3.9	12.0″	85%	1.396	0.728	326°06.6′	10°14.4′	0h 40.2m	2°31.5′
		15	−3.9	11.4″	89%	1.476	0.727	353°04.3′	27°09.8′	1h 43.2m	8°53.7′
		31	−3.9	10.8″	92%	1.546	0.726	13°45.6′	46°33.7′	2h 58.0m	15°25.7′
Mars	♂	10	1.7	4.0″	87%	2.337	1.602	103°20.5′	86°11.5′	5h 28.9m	24°16.6′
		20	1.7	3.9″	97%	2.395	1.612	108°02.1′	89°25.9′	5h 57.6m	24°30.3′
Jupiter	♃	15	−2.1	34.4″	100%	5.730	4.953	10°19.4′	17°27.2′	1h 06.1m	5°48.5′
Saturn	♄	15	0.1	18.2″	100%	9.108	10.026	257°06.3′	259°48.8′	17h 16.2m	−21°25.8′
Uranus	⛢	15	5.5	3.8″	100%	18.346	19.208	264°21.1′	266°04.7′	17h 43.2m	−23°32.0′
Neptune	♆	15	7.9	2.3″	100%	29.501	30.236	276°21.2′	277°48.5′	18h 34.0m	−22°09.8′
Pluto	♇	15	13.7	0.1″	100%	28.754	29.689	218°41.5′	218°21.7′	14h 45.2m	1°42.3′

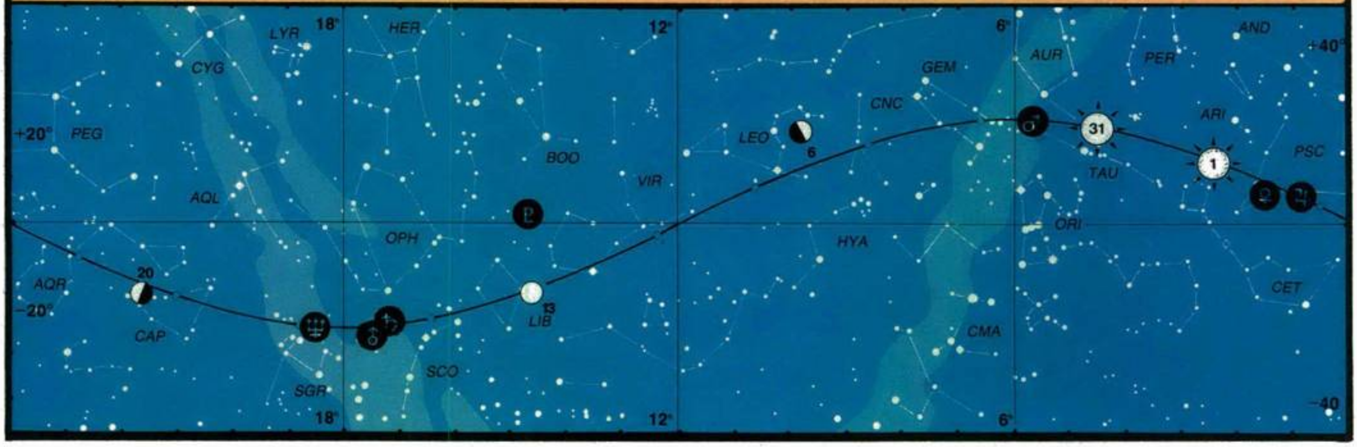

Mars
Mercury
Venus
Earth
Inner
Solar
System

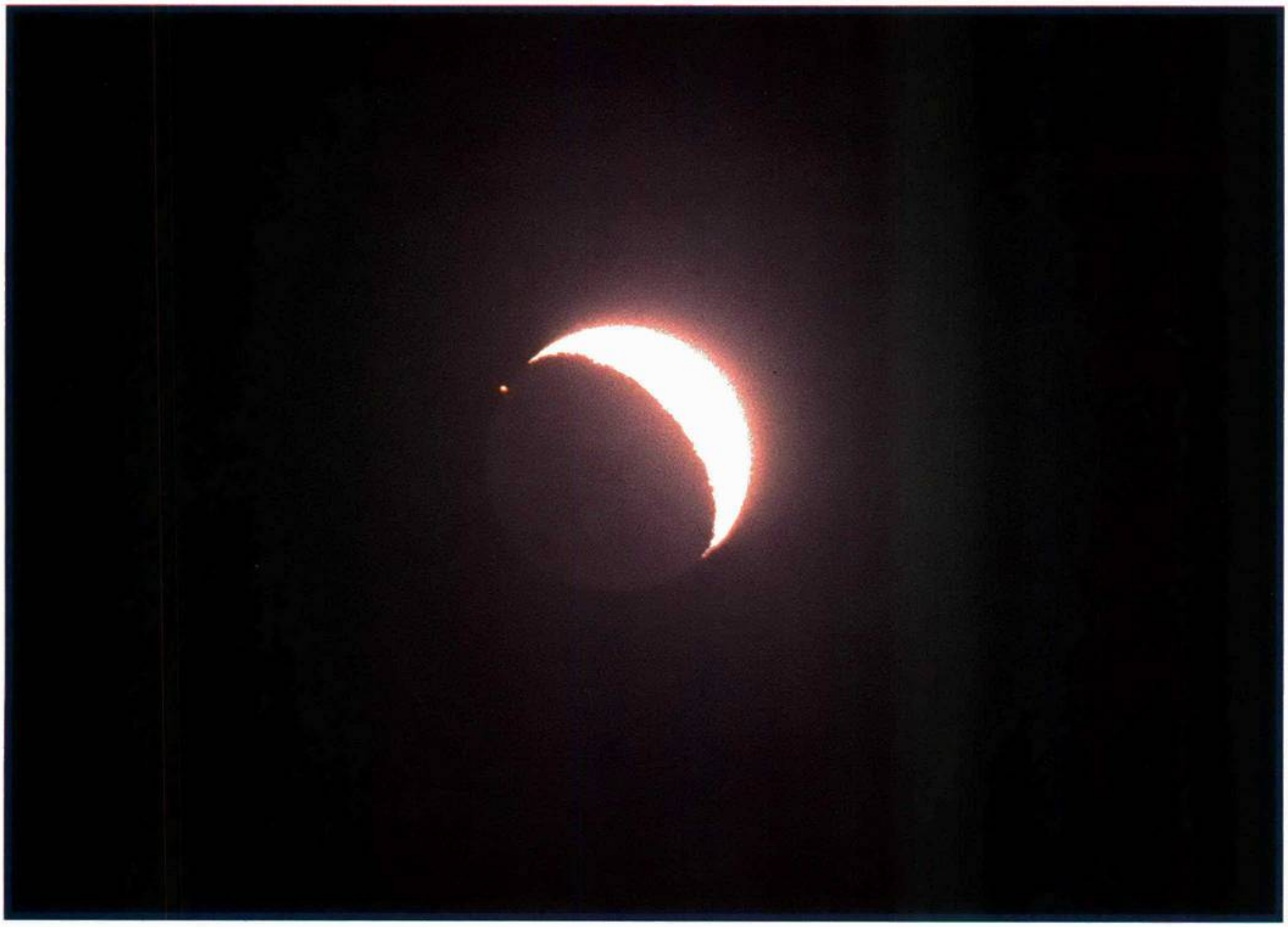

Mars
Jupiter
Earth
Pluto
Saturn
Outer
Solar
System
Uranus
Neptune

Moon Data

First Quarter............May 6 at 2h26m
Full Moon............May 13 at 12h50m
Last Quarter............May 20 at 4h02m
New Moon...........May 27 at 15h13m
First Quarter...........June 4 at 18h53m

Apogee: May 4 at 1h43m......404,700 km
Perigee: May 15 at 22h34m....363,624 km
Apogee: May 31 at 17h50m....405,627 km


LYR
18h
HER
12h
6h
AND
+40°
CYG
GEM
AUR
PER
CNC
+20°
PEG
LEO
6
31
ARI
PSC
BOO
VIR
1
TAU
AQL
ORI
OPH
HYA
AQR
20
CET
−20°
CAP
13
LIB
CMA
SCO
SGR
18h
12h
6h
−40



On the evening of January 25, the waning crescent Moon occulted the brilliant star Antares. This event was visible from the part of Central America directly north of South America. This photograph shows the view at 5:35 a.m. PST from the Santa Monica Mountains National Park in California. Martin D. Hale used a 5.5-inch f/3.6 Schmidt-Newtonian, Fujichrome 400 film, and a 1-second exposure.

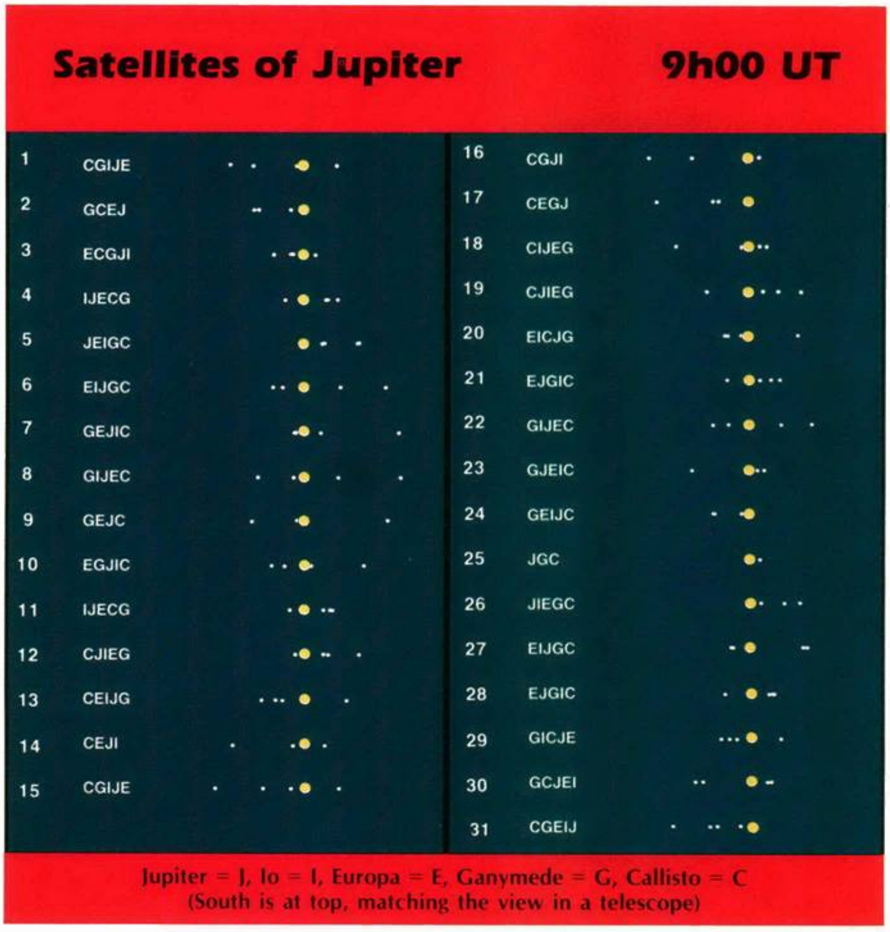
Mercury

Around May 13, Mercury will begin a five-week apparition in the evening sky. This is an excellent opportunity to turn your scope on this small, hot planet. The planet will be in the west-northwest after sunset, reaching a peak elevation of 11° (forty-five minutes after sunset) in early June. Mercury will be at least 4° high between May 18 and June 19. Since this elevation is still relatively low, you should expect to encounter distortion from the atmosphere: achieving a crisp focus will be difficult.

Mercury's brightness will steadily decrease from magnitude −1.2 on May 18 to 1.8 on June 19. In your scope medium magnifications (15x to 20x per inch of aperture) will reveal a small, cream-colored disk that is gibbous in mid-May and half-lit by the end of the month. Large scope views may hint at very faint, broad, dusky markings on the planet's surface.

Venus

To the naked eye Venus is prominent



Satellites of Jupiter **9h00 UT**

1	CGIJE	16	CGJI
2	GCEJ	17	CEGJ
3	ECGJI	18	CIJEG
4	IJECG	19	CJIEG
5	JEIGC	20	EICJG
6	EIJGC	21	EJGIC
7	GEJIC	22	GIJEC
8	GIJEC	23	GJEIC
9	GEJC	24	GEIJC
10	EGJIC	25	JGC
11	IJECG	26	JIEGC
12	CJIEG	27	EIJGC
13	CEIJG	28	EJGIC
14	CEJI	29	GICJE
15	CGIJE	30	GCJEI
		31	CGEIJ

Jupiter = J, Io = I, Europa = E, Ganymede = G, Callisto = C
(South is at top, matching the view in a telescope)

A Comet Wilson Ephemeris

Date	R.A. (2000)	Dec.	Dist. from ⊕ (AU)	Est. Mag.
May 20	8h18.1m	−30°12.3′	0.935	5.1
21	8h20.2m	−28°44.8′	0.963	5.2
22	8h22.2m	−27°22.5′	0.991	5.3
23	8h24.1m	−26°04.9′	1.020	5.4
24	8h25.8m	−24°51.8′	1.049	5.5
25	8h27.5m	−23°42.8′	1.078	5.5
26	8h29.0m	−22°37.6′	1.108	5.6
27	8h30.5m	−21°36.2′	1.138	5.7
28	8h32.0m	−20°38.0′	1.168	5.8
29	8h33.3m	−19°42.9′	1.199	5.9
30	8h34.3m	−18°50.7′	1.229	5.9
31	8h35.9m	−18°01.3′	1.260	6.0
June 1	8h37.1m	−17°14.4′	1.290	6.1
2	8h38.3m	−16°29.9′	1.321	6.2
3	8h39.4m	−15°47.5′	1.352	6.2
4	8h40.5m	−15°07.2′	1.382	6.3
5	8h41.6m	−14°28.9′	1.413	6.4

Data sources: Alan Hale (New Mexico State University), *IAU Circular #4294*, *Minor Planet Circulars* #11429 and #11444.

in the east just before sunrise, but its low elevation makes telescopic viewing difficult. It has an apparent diameter of about 11″ and appears gibbous; its brightness is magnitude −3.9.

Venus' conjunction with Jupiter on the 4th, with a minimum separation of 36′, will offer an interesting contrast between a bright but small Venus and a dimmer Jupiter that looms three times larger. Use low magnifications (5x to 10x per inch of aperture) to get both planets into the same field of view. Note how featureless Venus appears compared to Jupiter.

Mars

By the time the sky has darkened appreciably after sundown, magnitude 1.7 Mars is about 20° high in the west. Unfortunately a telescopic view won't show much more than the naked eye, because almost 2.5 astronomical units (375 million kilometers) lie between Earth and Mars. As a result the Red Planet appears hardly larger than Uranus and presents only dim markings that slowly drift across a tiny ocher disk.

Minor Planets

1 Ceres (magnitude 7.6) is moving retrograde in Sagittarius, where it will be difficult to locate amidst the star clutter of the Milky Way. (At the beginning of May Neptune lies about 2° to the northeast, but Ceres' motion is carrying it away from the planet.) Its positions:

1st: 18h 25m 26s, −22° 47.9′
10th: 18h 24m 15s, −23° 15.8′
20th: 18h 20m 23s, −23° 50.7′
30th: 18h 14m 01s, −24° 28.4′

Ceres rises around midnight local daylight time on the 15th.

2 Pallas (8.7) is at opposition on May 13 near the juncture of Hercules, Serpens Caput, and Corona Borealis. Its positions:

1st: 16h 14m 22s, 23° 25.0′
10th: 16h 07m 29s, 24° 52.5′
20th: 15h 59m 03s, 25° 58.1′
30th: 15h 50m 39s, 26° 28.1′

Pallas is visible all night.

3 Juno (10.5) is moving eastward in central Aquarius. Its positions:

1st: 21h 37m 56s, −4° 26.3′
10th: 21h 47m 19s, −3° 30.6′
20th: 21h 56m 44s, −2° 32.2′
30th: 22h 04m 54s, −1° 39.2′

Juno rises about 1 a.m. local daylight time on the 15th.

45 Eugenia (11.2) lies in southern Libra near the bright group of stars 36, 39, and 40 Librae. Its positions are:

1st: 15h 32m 04s, −26° 25.3′
10th: 15h 25m 26s, −26° 21.5′
20th: 15h 15m 22s, −26° 07.6′
30th: 15h 05m 54s, −25° 46.1′

Eugenia rises soon after sunset and is visible until shortly before sunrise.

To locate a minor planet, plot its dated positions (given for 0h UT) lightly in pencil on a good star map (*Sky Atlas 2000.0*, for example) and sketch a smooth curve linking the points. Then observe the starfield at low magnification and photograph or plot by hand what you see. Check the field a night or two later; the "star" that moved is it. (All minor planet coordinates are for the epoch 2000.0.)

Jupiter

Early in May Jupiter still hugs the eastern horizon just before sunrise (hence its conjunction with Venus), but it will rapidly rise higher each morning and become easier to view. Since details on the Jovian disk have fairly low contrast, they will be easier to see if you view the planet as twilight brightens. The best time to look depends on your equipment and the particular observing circumstances. But often twenty to thirty minutes before sunrise (or after sunset with an "evening" planet) is an ideal time. This is the moment when all the subtle details of the planet's cloud belts stand out with greatest clarity.

Saturn

Saturn reaches opposition on June 9, so it is easy to view this month. Rising an hour or so after sunset, the ringed planet is visible all night. In the first few days of May Saturn lies about ½° south of magnitude 4.4 Xi (ξ) Ophiuchi, and a low-power eyepiece will show them grouped together.

Saturn's rings are tipped open nearly to their fullest extent (maximum comes next year), but they will look pretty much as they do tonight for another two years. After that, their decreasing angle will become apparent as the rings change toward an edge-on aspect in 1995.

Uranus

Uranus lies about 1½° north of a point halfway between M-8, the Lagoon Nebula, and magnitude 3.3 Theta (θ) Ophiuchi. Uranus is at magnitude 5.5 and its 3.8″ disk has a distinctive blue-green color. (A finder chart appeared on page 108 of the January 1987 issue.)

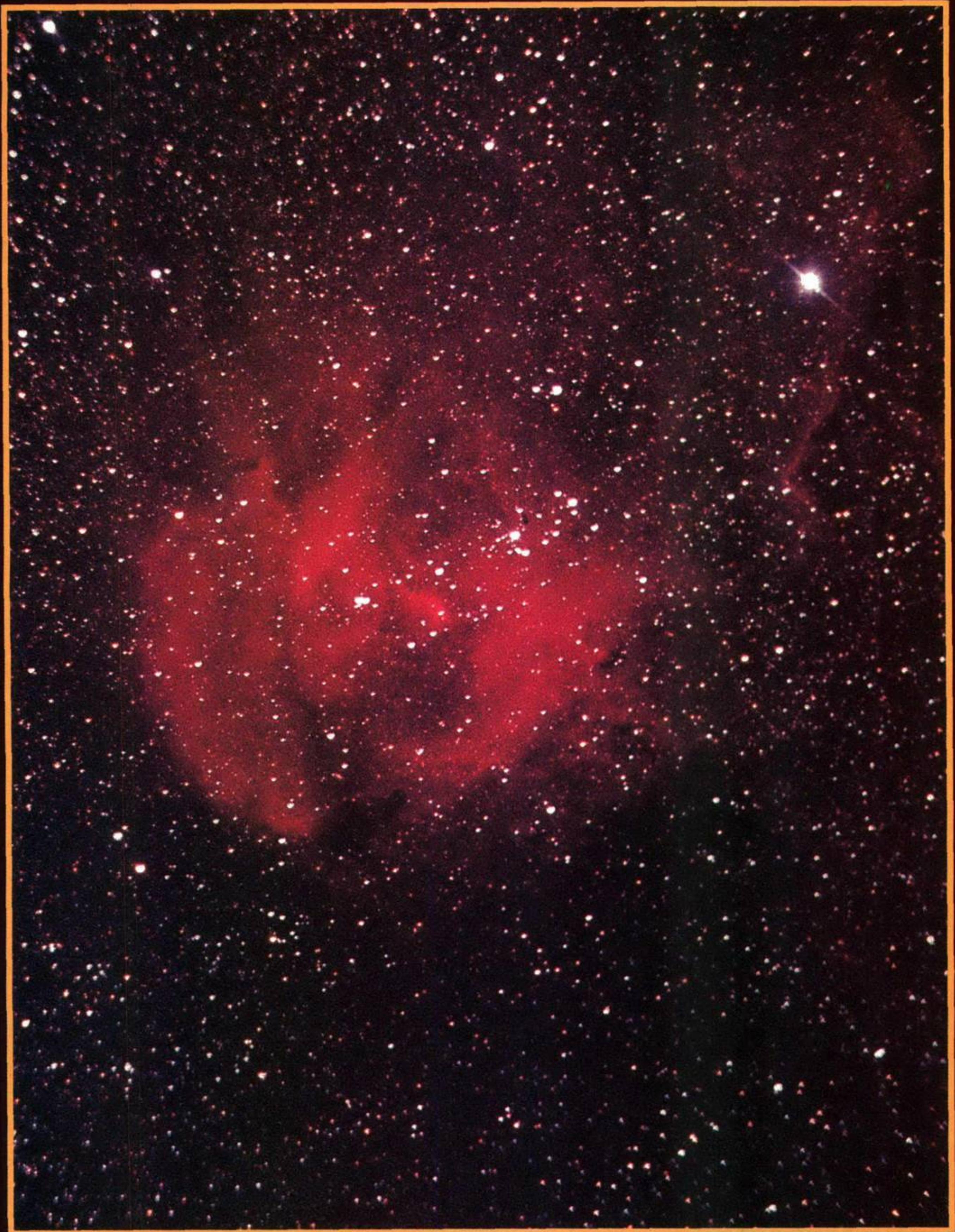
Neptune

Neptune lies on the opposite side of the Lagoon Nebula from Uranus. Locate it by centering your scope on Lambda (λ) Sagittarii and then scanning 1½° northeast to a small knot of stars near the globular cluster M-22. Neptune lies almost 2° due north from there, and its 2.2″ disk is at magnitude 7.9. (Page 108 of the January 1987 issue has a finder chart.)

Comet Wilson

Toward the end of May Comet Wilson will appear over the southern horizon and briefly swim into the eyepieces of Northern Hemisphere observers. Predictions indicate the comet will be most visible for northern observers during the "dark of the Moon" in late May and early June (see "Observing the Elusive Comet Wilson" by Alan Hale, Gazer's Gazette, January 1987.) Catching sight of the comet will be difficult because the comet will be around 5th magnitude and low in the southwest, setting soon after the Sun does. Nevertheless, this is a comet worth making the effort to see, because it appears to be making its first sunward trip since it left the Oort Cloud ages ago.

The box above provides the most up-to-date positions and brightness estimates at press time.



Australian Chris Floyd's photograph of the emission nebula IC 2944, surrounding the bright star Lambda (λ) Centauri, is this month's $100 "Best Astrophoto" winner. Floyd used a 10-inch f/4.5 Newtonian and a 15-minute exposure.

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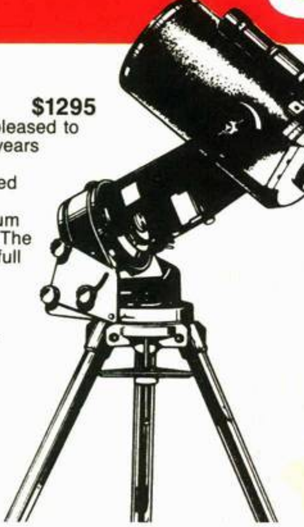

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